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ARMOUR, AND ITS ATTACK BY ARTILLERY.

BY

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PREFACE.

This work has already appeared in the form of papers contributed to the "Proceedings of the Royal Artillery Institution;" it is intended to facilitate instruction on the subject of armour and its destruction by artillery, and also to serve as a work of reference. With these objects in view, a list of contents and full index are supplied.

The work has grown out of lectures given by the author to the officers of the Royal Naval College at Greenwich, to the Advanced Class of Artillery Officers at Woolwich, and to the School of Gunnery at Shoeburyness.

The bulk of such matter as has originated with the author first appeared in the form of papers and reports on experiments written by him for the *Engineer*. The original wood blocks cut for these have been very kindly placed at the author's disposal. Many of these illustrations may now be found in English and foreign works, notably in Lord Brassey's "British Navy," Vol. II., and "Naval Annual," in "King's War Ships and Navies of the World," and Lieut. Very's "Development of Armor," Lieut. Jaques reports in the "Proceedings of the U.S. Naval Institute," besides Continental Professional Papers.

Everything connected with armour has been determined by experiment. It follows then that the greater part of this work is devoted to tracing the development of armour and the means devised for its destruction through courses of experiments conducted at Shoeburyness, Portsmouth, Spezia, Meppen, and elsewhere. In many cases the sketches of results were made by the author on the ground, in others photographs are copied. For his opportunities of witnessing experiments and obtaining information, the author is indebted to the Naval authorities, the Royal Engineers, the Italian Government, Herr Krupp, and particularly to officers of his old Corps, the Royal Artillery. It will be found that English trials occupy the principal place, and the author has to regret that he has nothing to offer on American experiments and but little on those of France. Happily, Very's admirable work is strong in these respects.

On many questions information is obtained from works which are quoted verbatim, often at considerable length, the writers names being of course given. Chapter III., Part II., consists of a reprint of the abbreviated report of the Bucharest Turret trial made by Major O'Callaghan, R.A., and Capt. Clarke, R.E.

The work is divided into two parts, namely, (I.) Armour Experiments. (II.) Armoured Structures, with short notes on manufacture and on results produced in action. This division enables additions to be made to each part without disarranging the numbering of the pages.

The author makes no attempt to predict what shape armour may take or whether even it may eventually disappear. The latter contingency does not at present appear likely, although a parallel might be drawn between the history of body armour and that for ships. In both instances entire casing has been given up, as the attack of fire-arms became too powerful for it. In both instances partial armour of a superior character has been retained to protect parts of the most vital importance, that is the head and chest of the soldier, and the engines, magazines, and water-line of the ship. The French Curassiers at Waterloo have been described[1] as appearing like men in complete armour with closed visors as they bent forward and charged up the hill, just as such a vessel as the *Shannon* is practically an armour clad when she engages head on to an enemy. The parallel is indeed very complete; for the protection afforded to the ship by the sea, and by contrivances, corresponds to that afforded to the soldier by the horse's head and saddle.

The author concludes by expressing the hope that must be shared with him by every thoughtful christian man that the action of armour may long remain chiefly the subject of scientific experiment, and but seldom be illustrated by the operations of war.

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[1] *See* Major Macready's account—Creasy's "Fifteen Decisive Battles."

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ERRATA.

p. 37, Part I.—Footnote :—
For "Admiral Fishbourne" *read* "Admiral Selwyn."

p. 98, Part I., *line* 29 :—
For "shot or" *read* "shot on."

p. 139, Part I., *line* 1 :—
For "Palliser steel shot," *read* "Palliser chilled shot."

SHORT HISTORY AND DESCRIPTION OF ARMOUR

AND ITS

ATTACK BY ARTILLERY.

CHAPTER I.

BRIEF HISTORY OF EARLY EXPERIMENTS.

On the history of the development of armour, Major-General Inglis, R.E.,[1] remarks that "every point, down to those of the nicest detail, has been based on experimental results," and that "in no subject that has ever been raised has mere opinion, unsupported by practical experience, proved so worthless as in this." It is not surprising, then, that the early experiments in many cases led to negative results; that is, they only proved the futility of the particular design or feature under trial. It is hardly likely to be generally useful to notice most of these experiments, which can best be studied in the printed proceedings of the Committee[2] by whom they were carried out. It is only necessary here to mention a few that stand out as landmarks, fixing the shape afterwards taken by the armoured structures themselves and the method of attacking them.[3]

In 1812, John Stevens, of New Jersey, designed a ship with a battery protected by inclined armour, and by 1841 his family, working at the same subject, had determined the resisting power of iron against the shot of the day fairly.[4]

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[1] *See* "Notes on Armoured Defences," a paper read at the R.A. Institution on April 29, 1880, by Colonel Inglis, R.E.

[2] "Special Committee on Iron," 1861, 1862, 1863, 1864; also "Ordnance Select Committee Proceedings."

[3] These are chiefly taken from "Notes on Armoured Defences," by Colonel Inglis. Some information on foreign and naval matters is quoted from "The Development of Armour for Naval Use," by Lieut. Very, U.S. Navy. The "Proceedings of the Special Committee on Iron" are also quoted.

[4] "Development of Armour," Very, p. 385.

In 1827,[1] an experiment of an unsuccessful character was made in Woolwich as to the resisting powers of masonry faced with wrought-iron bars, on a proposal by Major-General Ford, R.E.

In 1840, some Admiralty experiments to test the action of shot against iron-plates, backed by various substances, led to the conclusion that iron was a bad material for ships of war.

In 1841, General Paixhan[2] recommended the use of iron-plates in the United States.

In 1853,[3] masonry strengthened with iron was tried in the United States.

In 1855,[4] the French employed three iron-cased floating batteries against Kinburn, and before the end of the war between England and France with Russia the English had iron-clad batteries afloat.

From 1856 to 1859,[5] further experiments against iron plates took place: the 68-pr. smooth-bore gun attacking four inches of iron thickly backed with wood. In 1858, a wrought-iron shot passed through four inches of iron and wood backing. In 1861, a target representing the first English iron-clad frigate, the *Warrior,* was attacked by a Whitworth[6] 80-pr. rifled gun, firing a steel flat-headed shot. The *Warrior* target, which consisted of 4½ inches of wrought-iron, 18 inches of teak, and ¾-inch iron skin was indented and cracked, but not perforated by this shot.

Actual introduction of armour into the construction of ships of war.

As regards the actual introduction of armour into the construction of ships of war, Lieut. Very, with great justice, observes that the United States, which is often credited with taking the lead, owing probably to the part played by iron-clad ships in the American War, and especially to the well-known encounter between the *Merrimac* and the *Monitor,* was by no means the first. He observes:[7] "The orders for the construction of the *Monitor, Galena,* and new *Iron Sides*—the first iron-clads built for the United States—were issued in September, 1861. Prior to this time, as has been shown, England and France had each constructed a squadron of floating Batteries; these squadrons were quadrupled in size, and rendered doubly powerful in individual ships within the next four years. In 1858, the first squadron of sea-going armoured frigates—*Gloire, Normandie, Invincible,* and *Couronne*—was commenced in France, and scarcely were their keels laid when England responded to the advance with the *Warrior,* the *Black Prince,* the *Defence,* and *Resistance.* Before the United States Congress had considered the question of iron-clads, England, France, Spain, Italy, Austria,

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[1] "Report of Special Committee on Iron," 1861–1862, p. ix., &c.

[2] "Development of Armour for Naval Use," Very, p. 365.

[3] "Notes on Armoured Defences," Inglis, p. 1.

[4] *See* "Armoured Defences," Very's "Development of Armour," and "Proceedings of Special Committee on Iron," 1861–62.

[5] *See* "Armoured Defences" and "Proceedings of Special Committee," 1861–62.

[6] *See* "Proceedings of Special Committee," 1861–62. A 13-pr. shot at the present time would produce nearly the effect of this 80-pr.

[7] Very, "Development of Armour," p. 367.

Denmark, and the Southern Confederacy either had iron-clads afloat or on the stocks. Before Ericsson had submitted the design of the *Monitor* to the Naval Commission, Captain Cowper Coles had demonstrated the advantages of the turret, mounted on low freeboard iron-clad hulls, in public, to the naval experts of England (*see* 'Proceedings of the British United Service Institution,' June 29, 1860). Before the United States had closed the contract with Ericsson for the *Monitor*, the Danes had made one with Coles for the double-turreted sea-going ironclad *Rolf Krake*, the progenitor of the *Huascar*, and more closely resembling her than the *Nantucket* resembled the *Monitor*."

From about 1859 the manufacture of armour-plates progressed rapidly; the plates from about this date increasing steadily in thickness. In 1860, an 80-pr. Armstrong gun was fired against iron embrasures with plates 8 inches and 10 inches thick.[1] In 1861, various backings were tried, such as timber, cork, india-rubber, layers of wire, &c. From these, it was concluded that "while the hard materials improved the resisting power of the armour, they led to its being more injured by cracking, and to the giving way of fastenings."

Jones' inclined iron plates.

Jones' inclined iron plates were tried about this time; when it was concluded that a given weight of armour will protect a given vertical area equally well, whether in the form of a simple vertical plate, or of a thinner but necessarily larger inclined plate, the penetration of the shot being proportional to the sine of the angle at which it strikes the plate until the glancing angle is reached.

In 1861, the cupola of the *Trusty*, with 4½ inches of armour, was tried at Sheerness. It was in the form of a truncated cone. It resisted fire fairly well, and its machinery was not damaged.[2]

Special Committee on Iron.

In March, 1862, the Special Committee on Iron[3] made their first report, in which they state the following conclusions, among others: namely, that steel and steely-iron are bad materials for armour, while soft, but not necessarily costly, iron is best; that corrugations and bosses, designed to break shot on impact, are undesirable; that plates should be as large as practicable; that hard backing supported the plates at the expense of the bolts, whose functions are not only to hold the plates on but also to resist vibration and prevent buckling; that tongueing and grooving[4] the edges of plates tend to spread injury from plate to plate, and are bad; and that the effect of shot on plates is not proportional to the momentum of the former, but to the "energy," or "stored-up work," which may be expressed by $\frac{Wv^2}{2g}$, where W stands for the weight, and v the striking velocity of the shot, and g the force of gravity.[1]

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[1] "Notes on Armoured Defences," Inglis, p. 3.

[2] "Notes on Armoured Defences," Inglis, p. 9.

[3] The Committee consisted of the following:—President Sir J. C. D. Hay, R.N. (then Captain), Major Jervois, R.E., Colonel Henderson, R.A., Doctor Percy, Sir W. Fairbairn, and W. Pole, Esq. In this report the Committee divided their work into three sections: (I.) The collection and classification of results of experiments already carried out. (II.) The examination of witnesses possessing special knowledge. (III.) The carrying out of fresh experiments. The author thinks that few are aware of what valuable data and opinions are contained in the "Proceedings" of this Committee.

[4] Lieut. Very, in "Development of Armour," gives a capital illustration of complicated fitting of plate edges in the *Galena*, which succumbed under the fire of Fort Darling, p. 390.

Sir W. Fairbairn made some very interesting experiments on punching and crushing iron, which were submitted to the Committee; the results being given in an appendix to each of their three reports. From them it appeared that a flat punch clipped out a disc, which was more irregular in shape, and cleft or torn across where the support was less complete. A round-ended punch met with less resistance than a flat one at first, but before the perforation was complete it experienced about double the resistance, making a round-ended impression in the plate, and eventually driving out a bent disc torn across the centre. In the case of plates, which were thick in proportion to the diameter of the punch, a star or cross-shaped tear was made with the centre opposite to the point of the punch, but a small disc-shaped fragment of plate was generally detached at the centre of the cross. Hemispherical-ended pieces of iron were crushed with half the pressure necessary to crush flat-ended ones: namely, 26·82 tons instead of 55·36 tons per square inch.[2]

It may here be noticed that the soft iron having been adopted, a hard-pointed projectile was sooner or later almost certain to come in, in spite of the advantages at first presented by flat heads. Such a projectile would meet with but little resistance as its point entered, and by the time that it was so far in the plate that the resistance had approached the maximum, the head of the shot would be well supported, and its condition would be almost that of a cylindrical shot driving a pointed wedge in front of it. Whereas had a very hard plate been adopted the shot would meet with abrupt resistance directly its point touched the plate, and would experience a mechanical strain somewhat analogous to the outward thrust that falls on an arch. To this is probably to be attributed the ease with which a hemispherical-ended piece of iron is crushed.

Palliser shot.

The late Sir William Palliser seized on this idea and applied it to great advantage by the introduction of ogival-headed chilled-iron shot, to which he rightly gave sharper points than were afterwards approved for the Service. The advantage of a very long sharp point is apparent when it is borne in mind that the plate yields by bulging and tearing open at the back; for, in addition to the shot bearing the shock of impact better as noticed above, the actual point is applied more immediately to the spot where the tear is to commence, and thus the work of tearing is greatly facilitated. Palliser's projectiles were first tried at Shoeburyness on November 12, 1863.[1] Up to this time it may be noted that the heaviest rifled gun employed was a 10½-inch rifled gun, throwing a shot weighing 300 lbs.,[2] with a muzzle velocity of 1320 feet. There was also a 7-inch Whitworth 130-pr., and a 13-inch smooth-bore Horsfall gun.

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[1] Fairbairn suggested the following equation for punching:— $t = \sqrt{\frac{Wv^2}{CR}}$, in which t = the thickness of plate punched, W and v the weight and velocity of shot, R its semi-diameter, and C a constant to be determined by practice. This is the same equation as $\frac{Wv^2}{2g} = \pi D \times t^2 \times k$, where the energy of the shot is just equal to the circumference of hole made, multiplied into the square of the thickness of plate and a constant determined by practice. Nothing better than this equation exists at the present time for perforation.

[2] "Transactions and Report of Special Committee on Iron," 1862, p. 5.

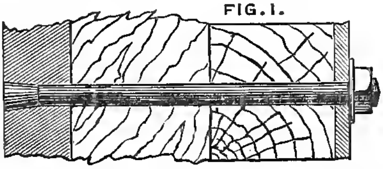
In America, before this time, iron-clad ships had been made from new designs, and also contrived by converting other vessels into armoured structures covered with railway iron, and the like. The *Merrimac*, the *Atalanta*, the *Tennessee*, the *Monitor*, the *New Ironsides*, the *Weehawken*, the *Montauk*, the *Nantucket*, the *Nahant*, the *Keokuk*,[3] and others, had played their parts in the war. Laminated armour, of which the chief recommendation had been ease of manufacture, was shown to be very inferior to solid wrought-iron plate.[4] Where perforation is effected by means of a pointed projectile, it may easily be seen that this is only what might be expected. The shot finds a passage through by tearing a ragged hole and bending back the corners, and these will bend back easily in the case of laminated armour, because the layers slip on each other and accommodate themselves to the bending, just as it is easier to bend up the corner of a book away from the back than one next the back where the edges of the leaves are fastened together.

Laminated armour.

Armour-bolts.

About this time, also, much had been learned with regard to armour-bolts. The early English ships, such as the *Warrior*, *Minotaur*, &c., had through-bolts with conical heads holding in the armour, and screwed ends nutted against the skin, the nut and conical head holding armour and skin together (Fig. 1). The French had adopted wood screws,[5] by which a bolt with a conical head held the armour to the backing, into which the screw held by a projecting thread (Fig. 2). The advantages of the French bolt[6] were that there was no langridge in action from heads flying off, and no leakage through a bolt-hole, and there was a saving of weight of nearly one-fourth on the bolt, which

FIG. 1.



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[1] "Report of Special Committee on Iron," 1863, p. 159.

[2] "Armoured Defences," Inglis, p. 3.

[3] *Vide* "Development of Armour," Very, p. 396, &c.

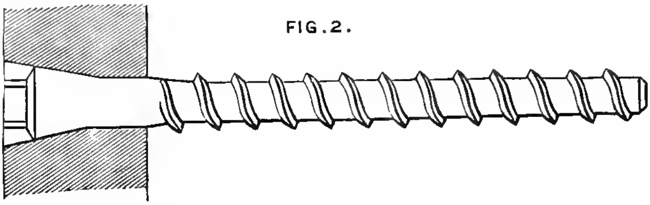
[4] About six inches of laminated was thought to be equal to four inches solid.

[5] Wood screws were tested severely with great success in America during the war, *see* "Development of Armour," Very, p. 402.

[6] "Development of Armour," Very, p. 380.

amounted to tons on the entire vessel. The importance of the second advantage is evident from the fact that numbers of casualties were caused in the American War by the bolt-ends and nuts.[1] Further, the strain was better distributed throughout the length of these bolts than in those of the English first pattern. The value of elastic washers to bolts was soon made apparent in England; but the first important step was made when, in 1862, Sir W Palliser proposed a projected thread of a screw to remedy the evil of weakness caused by cutting a thread—a weakness not at all measured by the mere diminution of cross section by the cut, for such a cut almost instituted a commencement of fracture, and certainly gave so limited and distinct a weak place that all the yielding of the bolt would take place there instead of being distributed along its length. This tendency to yield in one place is similarly encouraged by anything which may nip the bolt at any point. On this account, Major English, R.E., suggested leaving a clear space round the shank of the bolt between the bearings at the ends, and further proposed a spherical nut and bolt-head, and a hemispherical cup or seat in the plate, so that each end of the bolt should be capable of a ball-and-socket movement, which would enable it to accommodate itself to any slight displacement of the plates, which are united in pairs, that is, each plate is bolted only to the one next to it in plate-upon-plate targets (*vide* Fig. 3).

FIG. 2.



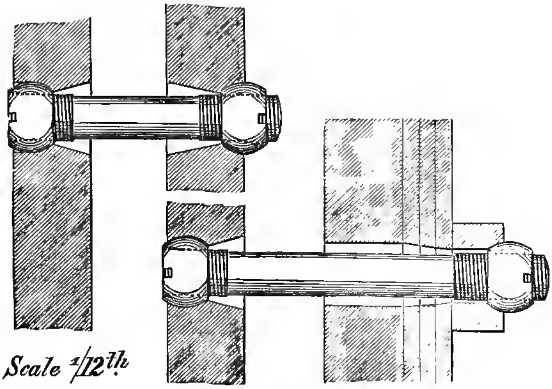


FIG. 3.

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[1] On the *Nahant*, the bolt nuts, flying from the inside of the pilot-house, disabled the pilot and mortally wounded the helmsman, disabling the steering-gear at the same time. In addition to these, five men in the turret were disabled by flying bolt nuts.—" Development of Armour," p. 396.

The *Chalmers*[1] and *Bellerophon*[1] targets had before this date been tried. These contained the feature of angle-iron stringers in the backing, intended to give support to the plates and rigidity to the structure, without the evil of transmitting the shock of impact to the bolts and fastenings more than necessary.

The introduction of heavier ordnance, such as the 13·3-inch gun, throwing a 600-lb. shot, capable of piercing the *Warrior* at a range exceeding two miles, caused thicker armour to come in. The *Hercules*, consequently, had 9-inch plates at her water-line, and a target representing her, with massive backing of teak and iron stringers, with ribs and skin, resisted the last-mentioned gun at 700 yards, and would have done so at much shorter ranges.[3]

Masonry casemates with ports in iron shields.

In 1865, as General Inglis relates,[4] "two complete masonry casemates with ports in iron shields were built at Shoeburyness. The masonry was 14 feet thick, consisting, generally, of a face of 6 to 8 feet of stone with brick-work behind it, the side-walls and vaulting of the casemates being of brick. The shield of one was a compound structure 12 feet long, 8 feet high, and altogether 21 inches thick (including 7 inches of wood); that of the other was made out of a solid rolled iron plate, 7 feet high, 6 feet wide, and 13½ inches thick. After the mounting, working, and firing of a 23-ton gun, and a 12-ton gun in the casemates as well as on the roofs, had proved the work to be suitable in arrangement for such guns, the front of the work was attacked by a battery of 7-inch, 8-inch, 9·22-inch, and 10-inch guns at ranges of 600 and 1000 yards, firing steel and cast-iron shot, some with hemispherical and some with elliptical heads.

"The general result of this trial was that after 33 hits the work began to become untenable, after 54 hits its fire would have been virtually silenced, and after 86 hits, of which 22 were on iron, the masonry front was destroyed, but the shields still offered a fair amount of protection. The aggregate of all the blows delivered came to 200,000 foot-tons, of which 52,000 were on iron.

"The issue of this experiment was of the utmost importance to the Service, because on it were based the decisions (1) that our most advanced and important sea-forts should be protected by walls consisting wholly of iron, and (2) that for other coast batteries masonry might be used, but that every gun casemate of these should have a shield affording protection against fire, equal, *at least*, to that of its own gun. A series of trials of plates of steel, and steel and iron combined, at this time showed that at this stage of the development of armour a simple rolled plate of soft iron formed the best shield."

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[1] *Chalmers* target, tried May 4, 1863, consisted of 3¾-inch iron plate on 10¾-inch backing of horizontal wood and iron stringers, then a 1¼-inch plate, and 3¾-inch wood, and ⅝-inch skin (iron).—"Proceedings of Committee," 1863, p. 183.

[2] The *Bellerophon* target, tried December 8, 1863, consisted of 6 inches iron, 10 inches wood backing with angle-iron stringers, and double layer of ¾-inch skin.—"Proceeding of Committee," 1863, p. 195.

[3] Inglis on "Armoured Defences," p. 4.

[4] *Ibid.*

In 1866, a *Royal Sovereign* turret was tried at Spithead with *Bellerophon* 12½-ton guns; the turret suffered, but not in its turning machinery.

Plate-upon-plate, or sandwich system.

In 1864,[1] steel plates supplied by the Thames Company, Brown & Co., the Parkgate Company, and Petin and Gaudet were tried in Russia without success. A very important feature now found its way into English armour, that is, the plate-upon-plate, or sandwich system. Colonel Inglis relates this in the following words:[2] "In consequence of the growing powers of battering ordnance, it now became evident that our land-works would require walls of considerable thicknesses of armour; but there were two main reasons why very thick armour-plates should not be used in them. In the first place, the manufacture of a very thick plate is not so complete as that of one of moderate thickness, or at least to make it as complete would involve an enormous increase of cost in plant and manufacture; and next, the thicker the plates the deeper the joints must be, and therefore the more points of undue weakness will the armour present. It therefore became important to see whether the required protection could not be gained without the use of very thick plates. Against doing this was the prevailing opinion, based chiefly on theoretical considerations, that a single plate of given thickness would offer something like twice the combined resistance of two plates each of half that thickness, or about three times the resistance of three plates making up the same total thickness, and so on. This view was entirely disputed by those who had to deal with these questions officially, but it became our business to prove its fallacy. This was done under the following circumstances: In 1867, a total thickness of 7 inches of iron disposed in one solid plate in two plates of 3½ inches, and in three equal thicknesses, instead of giving resistances of about 100, 50, and 33, gave effects more nearly as 100, 95, and 88 respectively. Next a 10-inch plate failed to stop a shot which was stopped by two 5-inch plates, and another 10-inch plate bore out this result.

"Again, in a comparison between a solid 15-inch plate and a wall made up of three 5-inch plates, the result was that, although the solid plate gave a somewhat better resistance to a single blow, the three-plate structure stood repeated blows better than the other. Also in 1871, two targets representing portions of walls of ships' turrets were tried at Shoeburyness. The one was protected by single 14-inch plates, the other by two thicknesses of armour 8 inches and 6 inches respectively, with 9 inches of timber between them. In other respects the targets were similar. After receiving the same amount of battering the armour of both was taken off, and the effect upon the inner skin of the two-plate target was unmistakeably less than that on the single-plate structure.

"It may also be mentioned that, more recently still, a structure composed of three thicknesses of 6½ inches of iron proved rather superior to a solid 16½-inch plate in stopping the 818 lb. shot of the Service 38-ton gun, striking with a velocity of about 1415 f.s.

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[1] "Development of Armour," Very, p. 466; "Notes on Armoured Defences," Inglis, p. 9.

[2] "Notes on Armoured Defences," Inglis, p. 5. It appears as if "plate-upon-plate" ought to refer to iron plates touching each other, and "sandwich" to similar plates with wood or other material between; but the words have not been so used.—*See* "Targets for Trial of Heavy Ordnance," p. 3, Inglis. Perhaps all targets containing more than one layer of iron may be included under the term plate-upon-plate, and those with the intervals between the plates filled with other material further distinguished, when necessary, by the term sandwich.

"In thus dealing with the subject, it must not be supposed that the formation of iron walls made up of a number of very thin plates was ever advocated by us. The trial of the boiler-plate targets, already mentioned, for ever disposed of that kind of construction.

"Also, it should be mentioned that the above trials of the plate-upon-plate system showed plainly that the most satisfactory results were not obtained when the surfaces of the armour were in contact, but that, on the contrary, some thickness of a softer and more elastic material between the plates was necessary to prevent their breaking under heavy blows.

"To settle the best proportions, quantity, and best nature of material to be interposed between armour-plates, a series of careful experiments were set on foot, and the result was that a uniform spacing of about 5 inches (to be slightly modified under certain circumstances) between the different plates in all structures was decided upon; and also, although an iron-concrete, made by working up together cast-iron borings, asphalte, bitumen, and pitch, gave the best result, mainly on account of its great weight, yet brickwork in asphalte, Portland cement, concrete, and hard wood proved so satisfactory that these materials have been adopted, as circumstances required, in all our armoured walls."

A word or two of explanation may be here useful. It has already been explained that the shot perforates the plate by forcing its way through, so that the plate is stretched over the shot's point, and forced back until it tears in the shape of a cross or star; the shot's point comes through in the centre, bending the corners of metal back, eventually tearing them off, the shot passing clean through. In the case of a wood layer between the plates, it has been established by a series of experiments that the wood should be sufficiently thick to prevent the plates jarring together and cracking, but not sufficiently thick to give room for the shot's point to clear itself of the bent edges of the first plate before it impinges on the second. Practically, 5 inches has been found a good thickness for the wood, and adopted generally in this country for plate-upon-plate sandwich armour. It is made up of two layers, one of 2½-inch planks laid horizontally, and the other of 2½-inch planks laid vertically. In the course of plate-upon-plate trials it was found that a very remarkable result was produced on chilled-iron shot, on passing through iron plates with air-spaces between them. Projectiles which perforated the front plate were found disintegrated, a small part adhering to the second plate, in a mass whose consistency was rather that of metal powder pressed together than of solid metal. This effect has been repeatedly produced; one or two cases are noticed in experiments given hereafter (*see* air-space targets).

Air-spaces.

Remarkable as this result was, it never led to any definite attempt to utilize air-spaces, because there was reason to believe that by means of shells the front plate might be blown entirely off, and also because steel projectiles were coming into use abroad, and on these air-spaces have not been found to produce the same effect.

CHAPTER II.

INTRODUCTION OF FORMULÆ FOR APPLICATION TO EXPERIMENTS.

THE destruction of armour by shot is an illustration of the "rule of work." The "stored-up work," or "striking energy" in the projectile being converted into destructive effect on the target in the measure in which the former is fairly brought to rest. There are, as might be expected, many causes contributing to complicate what otherwise would be a very simple question. The high velocity and great violence exerted produce effects which it is very difficult to measure. The shot itself often becomes shivered and heated, and work is lost by the actual motion imparted to fragments. These are necessarily subject to great variation, and hence it follows that there is a limit to the degree of accuracy with which results may be calculated, the most favourable conditions being probably such as to allow a shot to completely penetrate, or, as it is termed, *perforate* armour with but little spare force, the shot being unbroken and the pieces of plate detached without being violently projected to a distance.

It is well, however, to pause here before becoming occupied with any special forms of destruction of armour, each of which must be dealt with according to its nature.

From the beginning there existed two distinct systems on which armour might be destroyed—termed "*punching*" and "*racking*." On the first system the projectiles are driven completely through the armour, with the object of taking effect on the guns, men, and whatever may be behind it. On the second system, the armour itself is broken up and destroyed, leaving the structure it covered exposed to the effects of subsequent fire. The results obtained by complete punching, or perforation, are more direct and immediate. On the other hand, those obtained by racking are, as regards the armour itself and the future defence of the ship, more decisive, unless, in punching, shells can be made to pass intact through the armour and explode in the interior. The former system was originally followed in England, the latter in America, as being suited to the American cast-iron heavy guns discharging projectiles of great mass with low velocity. It was at one time supposed that racking had become nearly obsolete.[1] The early experiments with cast-iron and steel armour were very discouraging; and thick wrought-iron with wood backing was long thought to be the only form of armour that was likely to be employed, a form which is peculiarly capable of resisting racking, while it admits of being punched by suitable projectiles. Hence the English experiments for some years consisted almost wholly of trials as to the punching powers of certain individual guns and projectiles, and the resisting powers of structures consisting of wrought-iron supported by backing of different kinds; the chief variation in conditions being the increasing scale on which the experiments were conducted, owing to the ever-increasing power of the guns and thickness of the plates. Exceptions of course occurred, and the backing and the fastenings of the armour, and form and nature of the projectile were constantly studied; still, it has been mainly a question of punching wrought-iron in one or another form until late in 1876, when both chilled-iron and steel became the subject of more special trial on the Continent. These, it shortly appeared, did not admit of being punched like wrought-iron; while, on the other hand, it was possible to shiver them in a way that was impracticable with good wrought-iron. Steel and chilled-iron have now both of them been adopted to such an extent that racking deserves attention as fully as punching.

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[1] The distortion of turrets, as attempted in the *Glatton* experiment at Portland, in 1872, comes under the head of "racking" in the original sense.—See *Glatton* experiment.

This racking, however, is not generally of the same character as that originally advocated in America, for modern vessels or forts are covered with massive steel or chilled-iron armour which is liable to be broken and thus detached; whereas the early American iron-clad ships were protected not by the thick wrought-iron spoken of above, but by thin iron plates superimposed in layers, forming what is termed laminated armour. This, it was found, could be destroyed by bending, and so tearing open the ship's side.

To calculate the stored-up work, represented by injury done in racking in either form, is clearly much more difficult than in the case of *"perforation"* or complete penetration, though, no doubt, the rule of work is equally fulfilled in each case.[1] The question of partial penetration, effected on the punching system, is also a difficult one; it is, however, of much less importance than complete perforation. A shot entering wrought-iron does little injury, except at the immediate spot it strikes, for the nature of soft wrought-iron causes it to yield locally rather than to transmit the shock through its mass; consequently, with the exception of a little tearing at the back, the injury effected in wrought-iron is generally confined to the punching out of a hole; and in the case of partial penetration, this hole may often remain plugged up by the projectile. Thus, it follows that in most cases wrought-iron plates bear continued firing very well. They may allow projectiles to pass through them, but they hold well together and suffer little loss in future resisting power from perforation, and still less from partial penetration. Hence, seeing that a shot which stops mid-way in its course through wrought-iron plates can itself produce comparatively little injury to those behind such armour[1], and that it weakens it very little, it is the least important case of effect produced that has to be considered on service.

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[1] The author thinks that Very must misunderstand him. In his criticism on the author's U.S.I. paper—See "Development of Armour," pp. 460–461,—Very concludes by saying: "If Captain Browne's argument be followed to a logical conclusion, and it be assumed that the hardness of the steel be increased, whilst its other properties remain the same, then the same blow would shatter the plate much more, unless, of course, it be argued that the act of shattering absorbs energy, which cannot possibly be the case." The author had stated that steel had "a remarkable power of distributing into its mass the shock of impact," so as to stop the shot, but at the expense of extending the area of destruction. Perhaps the meaning is best explained by an illustration. At Spezia, in 1876, the 100-ton gun projectiles passed through the wrought-iron plates, fragments having still some velocity left in them, in the case of one fragment, 600 feet per second. Similar shot were stopped by the steel altogether, but the steel plates were completely broken up. The perforation in the wrought-iron had cost a certain quantity of energy, but the shot fragments had still some left in them and travelled on. The fracture of steel had absorbed all the striking energy, and had stopped the shot. If the precise action of fracture were understood, the energy expended in producing each part of each crack might be worked out, and the whole, with the breaking of shot, the heat developed, &c., would, no doubt, equal the striking energy of the projectile. The author, by the expression that the armour absorbed the shock "in the act of going to pieces," meant exactly what Very expresses by the words "It is the projectile-energy which has been transferred to the plate that causes it to go to pieces." The wrought-iron at point of impact gave back and pulled asunder. The steel stood up to the work, transmitting the shock from particle to particle, until it was distributed into a considerable mass of the plate, the material splitting in all directions. The author had observed that steel undoubtedly differed from wrought-iron in this power to distribute the shock. He had, however, doubted if a claim could be made for steel that

Perforation, meaning the actual passage[2] of the shot through the plate, may with advantage be first considered generally, so as to arrive at a formula sufficiently correct to enable the results of experiments to be noted and compared, before discussing them in detail. To this end it will also be necessary to notice generally the quality and behaviour of different kinds of projectiles.

Piercing of wrought-iron plates.

Wrought-iron plates owe much of their value to the fact that they do not transmit the shock to the bolts and adjacent parts of the structure, but absorb the blow locally. Hence they may be penetrated easily, but crack comparatively little, especially if supported by soft backing. Penetration is effected in various ways, depending on the form and nature of the projectile employed.

The appearance of a shot after impact accords with the supposition that it is subjected to pressure exerted in lines which lie in a normal direction to the surface of the head of the projectile as it forces its way through the armour. A spherical cast-iron shot invariably breaks

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a given quantity of stored-up work effected actually a smaller injury on it. That is, suppose the shock could be equally distributed through the wrought-iron, he doubted if it could be proved that it would break it up more than steel. The undoubted property possessed by the steel was power of *distribution* of shock from particle to particle, which was connected with its hardness. Subsequently, in a Paper for the R. A. Institution, April 13, 1883, the author expressed his belief that steel of some kind ought, in the long run, to beat wrought-iron (*see* quotation in Note, Chap. XI.), having greater ultimate tenacity and greater elongation; that is, although, in 1882, he questioned if actual superiority in resisting power had been proved, in 1883 he thought it ought to be found so in the long run.

[1] Chiefly effected in the flying off of bolt-heads.

[2] Exact *perforation* is when the shot just passes through with no spare energy to carry it further. This can hardly happen in practice, but sometimes a near approach to it is seen. If part of a projectile remains lodged, and part gets through with energy sufficient to have cleared the lodged portion, the energy has been the equivalent of exact perforation.

up. The anterior part, being under pressure, as shown in Fig. 4, commonly forms a wedge with the point presented towards the rear, upon which the posterior part coming under violent tensile strain splits itself, the front part being afterwards picked up as a fragment, such as that exhibited in Fig. 5. Of course a great part of the work stored up in the shot is thus wasted. A spherical wrought-iron or soft steel shot is subject to the same forces, speaking generally, but yields in a different way by spreading out, as shown in Fig. 6. A flat-headed projectile meets with resistance directly along lines parallel to its axis, hence there is no tendency to form a wedge-like anterior fragment. Sir J. Whitworth's projectiles, being made of steel, hold well together, flattening or setting-up slightly. Ogival-headed projectiles have little tendency to form a wedge out of the anterior portion under pressure of impact. At first the resistance is comparatively small, and it may be seen by Fig. 7, that, by the time the head has entered sufficiently far to meet with great resistance, the normal lines are in such directions that the shot is nearly in the position of a cylinder driving before it an ogival wedge, whose form, while available to open the armour, has little splitting reaction on the shot itself. The fractured head, Fig. 8, is an example of what is commonly produced

FIG. 4.

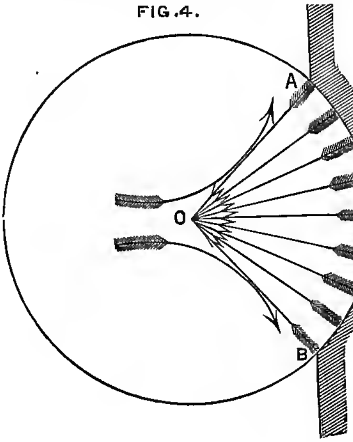
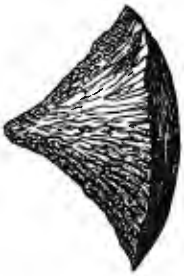


FIG. 5.



in soft armour. When made of chilled cast-iron, the projectile has comparatively little tenacity, and the posterior portion generally shivers

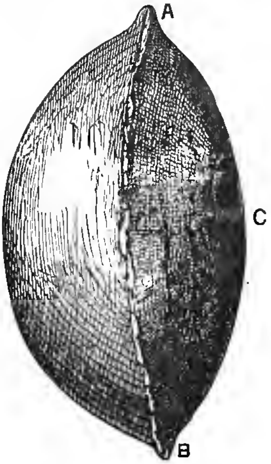


FIG. 6.

to pieces; nevertheless, the density and hardness of the metal are such that Palliser projectiles long held their own against all others.

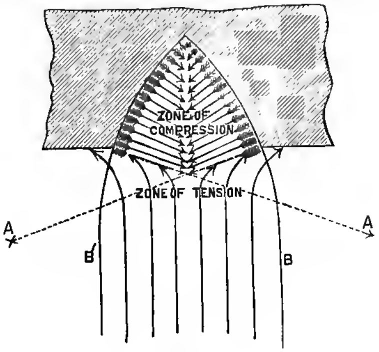
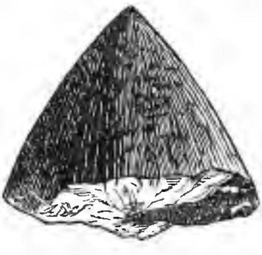


FIG. 7.

These projectiles effect a passage through wrought-iron by punching

FIG. 8.



or tearing a hole. Fairbairn, at a very early stage of the investigation of the question, suggested the following equation as, in a measure, representing the state of matters. This has since been employed, with modifications, by most officers who have dealt with armour-plate experiments in England. Captain Andrew Noble, Colonel W. H. Noble, R.A., and other officers connected with early Experimental Committees employed it. General Inglis, R.E., and Colonel Maitland, R.A., have latterly adopted other formulæ, and Major English, R.E., has from an early date used one of his own. Fairbairn's formula is, however, the one that ought first to be considered: it is as follows :—

Fairbairn's formula.

$$\frac{Wv^2}{2g} \pi D t^2 \mathrm{K};$$

where W = the weight of the shot, in lbs.

v = the striking velocity in feet per second.

g = the force of gravity = 32·19 feet per second.

D = the diameter or calibre of the shot, in inches.

t = the thickness of plate completely penetrated, in inches.

K = a certain constant whose value depends on the quality of the plate, &c.

As it is convenient to take the weight of the shot in pounds, and to give the stored-up work in foot-tons, the factor 2240 must be embodied in the denominator of the fraction on the left hand side of the equation, in order to bring the answer, which would otherwise be in foot-lbs., to foot-tons.

It may be seen that the left hand side of this equation, sometimes expressed by the letter "E," truly represents the stored-up work or energy of the projectile at the moment of impact.

The right hand side is open to objection; in fact it only claims to give an approximate and partly empirical solution of the question.

It may be seen that the assumption is made that the plate yields in a circle, πD, coinciding with the edge of the cross section of the projectile. Some have contended that the resistance is proportional to the area of the cross section, not to its circumference; and R^2 therefore enters into the expression employed by them. In certain cases of slight penetration into thick plates this may appear to be true; but it can be shown in cases of complete penetration, or anything nearly approaching it, that the circumferential assumption is more nearly correct.

Flat-headed, and even hemispherical-headed, projectiles punch holes in plates by driving out the piece against which they impinge; thus in separating it from the rest of the plate they clearly tear the iron through in a circle, whose circumference is expressed by πD, as seen in equation above. The ogival point finds its way through the plate in a line in prolongation of the shot's axis: the head tearing the plate open, and bending it aside in all directions. If wrought-iron plates that have been partially penetrated by ogival shot be examined, it will be found that the plate first yields by bending back opposite to the shot's point, tearing open in the form of a star or cross. This will be particularly well shown by and bye in Fig. 6, *Nettle* Trials, Chap. V., "Back view of wrought-iron standard plate." As the shot proceeds, it bends back the corners of the plate thus formed until they break off, leaving a circular hole, probably less than the full diameter of the cross section of the projectile, but easily enlarged so as to allow the latter to pass through. This action requires special notice, as having an important bearing on the plate-upon-plate system. On this principle a plate is torn through along lines whose total length may be expressed as $2D + \pi D$, supposing the plate opens in four cracks at the back. Theoretically, then, the flat-headed shot ought to get through a plate with less resistance than the ogival, if it was exactly a case of clean punching; and this has been pleaded in favour of the former, when an unbacked plate is fired at. Obviously, however, the rough disc of iron which is driven out in front of the flat-headed shot meets with enormous resistance as it gets foul in the backing; while the clean point of the ogival-headed shot, which has disposed of the plate in the manner described, cleaves its way easily through backing and skin; and the case becomes stronger where the armour consists of several layers of plate and backing.

Further, a sharp point has so great an advantage in commencing a tear, that for direct penetration of wrought-iron flat-headed projectiles have long since been abandoned, even by Sir Joseph Whitworth, who has warmly advocated their use for certain other purposes.

The truth of the equation given above depends on two assumptions, which are incorrect in a greater or less degree :—

1st. That the work done on the plate is proportional to the circumference of the hole made.

2nd. That the resistance of the plate is proportional to the square of its thickness.

The first of these two is a rough approach to what actually takes place. The second is confessedly empirical, and is modified by almost every one, according to their experience. For a long time this formula was employed in the Department of the Director of Artillery, in the following shape :—

$$\frac{Wv^2}{2g} = \pi D t^{1\cdot6} \times 2\cdot53.$$

Here $K = 2\cdot53$, and t is raised to the $1\cdot6$ power empirically.

The factor 2240 being, as above noticed, employed always in the denominator of the fraction on the right hand side, when W is put for the weight of the projectile in pounds. Of course all the constant parts of this expression might be included in one term; it is convenient however sometimes not to do so.

It may be required to obtain simply the total energy "E" of the shot on striking, in order to ascertain the racking effect produced on steel or chilled-iron, which cannot be punched. For example, if it were wished to compare the relative penetrating and racking powers of the English 38-ton gun and Krupp's more modern 24 centimetre (9·45-in.) gun, it would be found that the thickness of wrought-iron plate which each would penetrate would be about equal, but the relation of energy of the former to that of the latter would be about 11¼ to 8½, which would represent their probable relative powers of smashing up steel or chilled iron.

Another standard of comparison has also been employed, namely, the energy per inch circumference, written as "*e*"[1]. The value of this depends on the supposition that the plate is punched or sheared at the circumference of the projectile, and therefore resists the passage of the shot in proportion to the circumference of the hole that the shot makes. On this supposition we may find "*e*," the "penetrating figure," as it is called, of any shield; that is, the work necessary to shear each inch of that plate; and it will follow that any projectile with that quantum of energy per inch circumference will penetrate that shield. This is sometimes applied to a structure consisting of plate and backing. Thus 53 was abundantly proved to be the necessary figure for the *Warrior*; that is to say, it was found that any projectile from any gun having 53 tons energy per inch circumference was capable of perforating the *Warrior* target.

The formula we have presented above, then, might be used without much increase of trouble, giving these three successive results, viz.:—*first*, "*E*" the *total energy*, representing truly the actual blow, and being available for *racking*; *second*, "*e*" the energy per inch circumference, or *penetrating figure*, which allows ready application to any structure, single or compound, whose figure has been ascertained practically: *third*, "*t*" the actual thickness of wrought-iron in a single plate which can be *perforated* under the given conditions.

These results, obtained by the equation given above, as employed in the Director of Artillery's Department, were very nearly correct for the thinner kinds of armour and the projectiles used until the last few years; and, by a curious coincidence, they maintained their credit better than they deserved, with any who were imperfectly informed; for, as the armour grew thicker, the so-called "plate-upon-plate" or sandwich system, consisting of alternate layers of iron and wood backing, came in, as described in Chapter I.; and it happened that while the increase of total thickness in iron was itself adding to the power of resistance at a greater rate than allowed for in the formula as stated above, the division of the iron into three or four layers gave a falling off of actual power to resist perforation to an extent that very nearly compensated for the extra rate of increase just noticed.

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[1] So expressed in "R. N. Gunnery Manual," 1880. In Major W. H. Noble's Report, in 1866, this is designated by "ρ."

For these plate-upon-plate targets, General Inglis established the following approximate rule.[1] The resistance to perforation of any given thickness of wrought-iron armour, made up of single, double, or three layers of iron, with about 5 inches of wood between them, is proportionate to the numbers 100, 96, and 89. Thus a result obtained for a single or solid plate may be corrected to apply to a double plate by multiplying by 100, and dividing by 12 and 8, and sufficiently correctly for three thicknesses by multiplying by 10 and dividing by 9.

It was found that the modification of Fairbairn's formula with t, raised to the power 1·6, does not give correct results when the power of the gun is sufficient to deal with thick plates, say equal to 1¼ diameters of the shot and upwards. Consequently other formulæ have been devised. It will be found, however, that Fairbairn's formula in its original form, with t raised to the second power, gives results requiring but slight correction for the perforation of thick plates, and for all kinds of armour it needs probably as little empirical correction as any formula known.

It may be well to illustrate what has been said, by working out one example fully;[2] a simple case is furnished by the firing of the 38-ton gun, 12·5-inch calibre, at a solid unbacked wrought-iron plate 16·5 inches thick, on August 1st, 1877.

Here weight of projectile, $W = 817$ lbs.

Striking velocity …… $v = 1410$ feet.

Diameter of shot, … $D = 12{\cdot}43$ inches.

Fairbairn's old formula is thickness perforated, $t = \sqrt{\frac{Wv^2}{2g} \times \frac{1}{\pi D} \times \frac{1}{K}}$.

Writing the factors inside the root in a convenient shape to find successively the total striking energy E, that is $\frac{Wv^2}{2g}$; then the energy per inch circumference e, that is, $\frac{Wv^2}{2g} \times \frac{1}{\pi D}$; and finally the total thickness that can be perforated t. These, as has been noticed, are all useful functions, and it is easy to follow a process bringing them out in succession.

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[1] *Vide* previous chapter.

[2] Four-figure Logarithms are employed; they are accurate enough for the purpose. Much time is saved by using a card with the logs all on one side of it, so as to prevent the necessity of turning over leaves. Log tables of this nature were printed by the R. A. Institution, on Professor Bashforth's suggestion. Separate tables are supplied for finding logs to numbers and numbers to logs. This is convenient, but the single table given in the succeeding chapter is of course sufficient.

Here then,—

$$\begin{array}{rl}
\text{Log } 2 & = 0{\cdot}3010 \\
\text{Log } g^{*} & = 1{\cdot}5077 \\
\text{Log } 2240^{\dagger} & = 3{\cdot}3503 \\
\hline
\text{Log } 2g, \text{ \&c.,} & = 5{\cdot}1590 \\
\hline
\end{array}$$

$$\begin{array}{rl}
\text{Log } \pi \;\ldots & = 0{\cdot}4971 \\
\text{Log } 12{\cdot}43 \ldots & = 1{\cdot}0945 \\
\hline
\text{Log } \pi D \quad\ldots & = 1{\cdot}5916 \\
\hline
\end{array}$$

$$\begin{array}{rcl}
\text{Log } W (817 \text{ lbs.}) = & & 2{\cdot}9122 \\
2 \text{ Log } v \text{ (1410 feet)} = & & \left\{\begin{array}{l} 3{\cdot}1492 \\ 3{\cdot}1492 \end{array}\right. \\
\hline
\text{Log } Wv^2 \quad\ldots\quad\ldots & = & 9{\cdot}2106 \\
\text{Log } 2g, \text{ \&c.} \ldots\quad\ldots & = & 5{\cdot}1590 \\
\hline
\text{Total energy } \underline{E = 11263} \text{ foot-tons}\ldots\quad\ldots & = & 4{\cdot}0516 \\
\text{Log } \pi D \quad\ldots\quad\ldots & = & 1{\cdot}5916 \\
\hline
\text{Energy per inch } \underline{e = 288{\cdot}4} \quad\ldots\quad\ldots\quad\ldots & = & 2{\cdot}4600 \\
\end{array}$$

If the square root of this were taken without any correction the result would be $t = 16{\cdot}98$ inches; but to prevent the danger of readers casually using this as a type when thus imperfectly given, a slight correction, K, is made on a plan explained in next chapter.

Repeating then,—

$$\begin{array}{rr}
e = 288{\cdot}4 = & 2{\cdot}4600 \\
\log k = & \bar{1}{\cdot}9845 \\
\hline
\text{inches} & 2\,)\;2{\cdot}4755 \\
\hline
t = 17{\cdot}29 \ldots & 1{\cdot}2378 \\
\end{array}$$

Fairbairn's formula, as modified and used for some years in the Director of Artillery's Department is, as noticed above,—

$$t = \sqrt[1\cdot6]{\frac{Wv^2}{2g} \times \frac{1}{\pi D} \times \frac{1}{2{\cdot}53}}.$$

That is to say, it differs only from the above in the last process, when a different root and constant are employed, as follows:—

$$\begin{array}{rr}
e = 288{\cdot}4 = & 2{\cdot}4600 \\
\log 2{\cdot}53 = & 0{\cdot}4031 \\
\hline
1{\cdot}6 \left\{\begin{array}{r} 4)\;2{\cdot}0569 \\ \hline {\cdot}4)\;\;{\cdot}51423 \end{array}\right. & \\
\hline
t = 19{\cdot}31 \text{ (inches)} & \ldots\; 1{\cdot}2856 \\
\end{array}$$

---

* g is taken as 32·19.

† To bring the stored-up work or energy to foot-tons. The weight of the shot is always given in lbs., and unless this factor were used to bring lbs. to tons the answer would come out in ft.-lbs.

The results is, in this case, much further from the truth than the results given by Fairbairn's old equation, without the application of any correction K. This would be supported by any of the later formulæ used, and it is borne out by the result on this occasion, when the projectile got through the plate, breaking to pieces and having a little spare work in it, so that Inglis[1] estimated it as able to perforate a plate from 17 to 17·5 inches thick.[2]

It may be seen that Log $2g$, &c., $= 5{\cdot}1590$, and Log $\pi = 0{\cdot}4971$ are constants available for all examples. The calculation of results of experiments is further discussed in the next chapter.

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[1] That is to say, Inglis estimated that from 17 to 17½ inches solid plate would correspond to a certain sandwich target (No. 40) which was as nearly as possible a match for this shot; *see* Inglis' paper on "Targets for Heavy Ordnance," R.E. Institution, 1877.

[2] A diagram, brought out by Colonel Maitland, gives 17·14 inches, and one by Colonel Inglis 17·2 inches. A rule of thumb, recommended for rough estimation, by the author, gives 17·6 inches (for these see next chapter).

CHAPTER III.

CALCULATION AND ESTIMATION OF THE POWERS OF GUNS AGAINST ARMOUR.

For the sake of distinction, Armour may be divided into two classes, "*soft*" and "*hard.*" Under the head of *soft* armour, may be included all shields which admit of *perforation*, which, when possible, is the best method of attack. *Soft* armour then includes all kinds consisting of wrought-iron only, whether laminated, plate-upon-plate, or solid. Occasionally a steel or steel-faced plate has had a hole made completely through it without breaking it up,[1] but this is not generally possible. Wrought-iron was universally employed until chilled iron armour was adopted for certain land forts on the continent. This was first tried in 1868 with success, and in 1873 it met with very marked approval.[2] After the Spezia trials of December, 1876,[3] steel and steel-faced armour came gradually into use. Up to that time, our experiments in England were almost entirely confined to the problem of the perforation of wrought-iron. And even now perforation is kept in view with steel-faced plates in a measure, for a shot is generally considered to be a match for a steel-faced plate when it is capable of *perforating* some estimated equivalent thickness of wrought-iron. Suppose, however, that such a relation can be established, its application is limited to the few cases when perforation without much fracture is effected, and may greatly mislead any one who uses it indiscriminately, for the following reason:—Power of perforation varies inversely with the diameter of the hole made. Thus a shot of less energy than another may perforate the same thickness of armour if its calibre is less, because it does not require to make so large a hole. Thus, as mentioned in the last chapter, the 9·45-in. Krupp gun in 1879, had about the same power of perforation as the 12·5-in. Woolwich gun, namely, about 18 inches; and would be considered a match for the same plate. If, however, armour is too hard to perforate, and yields by breaking up instead, it appears doubtful if the smaller calibre possesses any advantage over the other. The work of "smashing" appears to be more likely proportional to the striking energy or stored-up work. Thus, in the case above quoted, the 12·5-in. shot has more energy than the 9·45-in. shot, in the proportion of nearly 3 to 2, and might break up armour accordingly. So, again, the 100-ton M.L. gun at 2200 yards had about the same perforation as the 43-ton B.L. gun at the muzzle, namely, about 24 inches of iron.[1] Its energy, however, is greater in the proportion of 3 to 2;[2] and the larger projectile has this advantage with a velocity of only 1500 feet per second, while that of the smaller one is over 2000 feet. It is quite conceivable then that the former would hold better together, and thus deliver perhaps double the blow of the smaller one before breaking up. In such a case, then, it appears that the standard of perforation is a very erroneous one. It is, however, the only standard which has been definitely worked out, and on it our diagrams and rules are based. They must therefore be considered correct only when applied to cases of *soft* armour. *Hard* armour, which cannot be perforated, includes chilled cast-iron, and, in most cases, steel-faced armour and steel, though the latter may be made[3] so soft as to approach wrought-iron, and so be perforated in a fairly clean hole. This, however, has not been the character of most of the steel plates hitherto tried. A projectile may drive its point a short distance into *hard* steel, but eventually it acts as a conical wedge splitting up the plate, and the shot breaks up before the entire head enters the plate, so that the size of the calibre probably affects the problem less than the shape of point, and it appears that the main question is that of the striking energy, modified by the shot's power to hold together, which again depends directly on tenacity of metal, and possibly inversely on some function of the striking velocity. In Reports on Experiments, General Inglis sometimes gives the average number of foot-tons work sustained by plates per square foot,[4] but such information has never been brought into a shape to furnish data to guide Officers in the attack of *hard* armour. In short, the detailed information below will be seen to apply altogether to the perforation of *soft* armour. At the present time it would apply to the attack of the great bulk of old fashioned armour-plated ships, which are cased in wrought-iron. It would not apply to the Italian vessels, *Duilio, Dandolo, Italia* and *Lepanto,*[1] nor to any French or other vessel which may carry steel armour, unless the steel is very soft, as undoubtedly is occasionally the case; nor would it apply to the case of chilled-iron forts. On these there is but little to be said. Some remarks and calculations, however, on the results of recent trials against *hard* armour will be found hereafter.

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[1] *Vide* trial of Palliser improved projectiles in 1882 and 1883, and Brown's plate tested at Shoeburyness in 1882.—Chap. VI.

[2] In Prussia against an 11-inch gun (28^{cm}), and in 1874 at Tegel and Cannes.—*Vide* Chap. VIII.

[3] *Vide* Chap. V.

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[1] As originally laid down.—*vide* Inglis' diagram. Of course these perforations increase as powder and projectiles improve.

[2] Viz.:—31,200 against 19,800 foot-tons. In March, 1883, at Copenhagen, a Krupp 15^{cm} (5¾-in.) gun, and an Armstrong old-type 9-inch gun were fired at the same target.—*vide* Very. Their energies per inch circumference were nearly equal, namely, 123 and 118 foot-tons, respectively, but their total energies were 5,760 and 16,403 foot-tons The smashing powers would be probably in the latter ratio.

[3] *Vide* Spezia trials, 1884, hereafter.

[4] *Vide* Report of Sub-Committee on Plates and Projectiles, p. 17; also Major O'Callaghan's paper, R. A. I. Proceedings, Vol. XII., Major English's method of calculating effects took into account the mass of the Plate.

Perforation through Soft Armour.

An admirable official Report on the "Penetration of iron armour plates by steel shot," was compiled in 1866 by Colonel W. H. Noble, R.A. A diagram showing the ranges at which British and Foreign armour-clad ships might be perforated, was brought out on a suggestion made by Colonel Forde, R.A., in the "Engineer," and also in the "United Service Institution Proceedings" by the author in 1872; and in 1873, Colonel Noble prepared a diagram on a different principle, by authority, which was once afterwards corrected and completed to include the 80-ton gun, but all are now out of date.

A memorandum on the perforation of solid unbacked wrought-iron plates by direct fire was drawn up by the Sub-Committee on Plates and Projectiles in 1881, containing diagrams constructed by General Inglis, R.E., and Colonel Maitland, R.A., from which the effect of projectiles, fired under various conditions, could be read off easily. The text of this memorandum stated that certain conclusions had been arrived at by the Committee, with regard to data on which to calculate perforation supplied by the very complete series of experiments made with the Elswick 6-in. and 8-in. guns by this Committee. Both Colonel Maitland and General Inglis based their calculations on the relation borne by the diameter of shot (or calibre of gun) to the thickness of plate perforated. The two diagrams can be best used in different ways. Inglis' diagram is undoubtedly the most readily understood, and most easily used, but its use is confined to the case of shot of a given weight, fired from those guns which may be entered on the diagram. The result is directly read off, and no explanation is here required.[2] Maitland's diagram is available for problems with any gun and projectile, and it should be understood that in using it an actual process of calculation is performed, which may be regarded as equal to any in accuracy, and when reduced to a system by the use of tables it is far more rapidly and easily performed than any other, when perforation is the result sought.

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[1] Schneider's plates may yield by perforation accompanied by cracking, which would make calculation difficult.

[2] This diagram might be used on service readily if supplied.—*Vide* "Use" under *Practical Directions.*

Maitland based his operations on the fact that the scale on which plate experiments are conducted does not materially affect the mechanical conditions of the question. He therefore works the problem and obtains a result "*K*" in calibres, or more strictly in diameters of the shot. Such a result can of course be brought out in inches by multiplying it by the number of inches in the particular calibre or diameter required.

Thus, if *K* be 1·5, it would imply that under those conditions a 6-in. projectile would perforate 9 inches, a 12-in. projectile 18 inches, and so on.

Maitland took the proportion of weight and calibre (or sectional density) of projectiles, with which the most reliable experiments were made by the Committee, that is, $\frac{W}{d^3} = 0·37$ as a standard co-efficient, and he made for these conditions a diagram, from which was read off the factor *K*, which, when multiplied by the calibre or diameter of the shot in question, gave the perforation required.

With shot whose $\frac{W}{d^3}$ does not equal 0·37, he formerly required a second diagram to reduce the actual velocity to what would bear equivalent velocity if $\frac{W}{d^3}$ were equal to 0·37, as a preliminary operation. The use of the first mentioned diagram follows. These two operations are very quickly performed and give good results.

Maitland subsequently brought out a large card diagram, which by means of a brass bar pivoting at one end, can be set so as to combine the two operations above in one. When the striking velocity and the the value of $\frac{W}{d^3}$ are known, the factor *K* is immediately found, which multiplied by the calibre gives the perforation in inches. In addition to this, the same card, together with a wood scale, can be used to find the remaining velocity at any range, when the initial velocity is given, and also to find the time of flight. For practical purposes on service this diagram might be reduced in size, the gain in convenience would more than compensate for any loss in accuracy. Both Inglis and Maitland calculate results on systems of their own, apart from the use of diagrams. Between Inglis' diagram and his formula, there does not appear to be any necessary relation. The diagram is based simply on results obtained by practice. The fact that the curves of each gun are nearly straight lines goes to prove that the terms on which the abscissæ and ordinates, t and v, are based, are in direct proportion to one another, and the same power; in other words, that v^2 and t^2 enter into the question as in Fairbairn's formula. Inglis' own formula differs generally from this. General Inglis lays down, in calculating problems, that for a given relation of t (the thickness of plate just perforated) to d (the diameter of shot) a given factor multiplied by the number of cubic inches of iron removed in forming a cylindrical hole in the plate will give the required striking velocity. When the relation of t to d changes, the factor changes; but as long as this relation remains the same, it is immaterial on what scale the experiment is made. He gives the following table :—

Proportion of thickness of plate (t) to diameter of shot (d) $\frac{t}{d}$	Energy required to remove each cubic inch of iron in forming a cylindrical hole through plate.—c.
	foot-tons.
·5	2·6
·6	3·0
·7	3·3
·8	3·6
·9	3·9
1·0	4·2
1·1	4·5
1·2	4·8
1·3	5·1
1·4	5·4
1·5	5·7
1·6	6·0
1·7	6·3
1·8	6·6
1·9	6·9
2·0	7·3

Taking W=weight, v=striking velocity, and g force of gravity, Inglis gives the following formula for calculation.

$$\frac{Wv^2}{2g} = d^2 \times \frac{\pi}{4} \times t \times c; \quad \ldots \quad \ldots \quad \ldots \quad \text{(Eq. 1)}$$

$$\therefore\ v = d\sqrt{\frac{t \times c \times \frac{\pi}{4} \times 2g.}{w}}$$

Example.—Find the velocity at which an 8-inch shot (d = 7·97 in.) of 182½ lbs. weight will perforate a 12-inch wrought-iron plate :—

Here $\frac{t}{d} = \frac{12}{7{\cdot}97} = 1{\cdot}5$, whose corresponding $c = 5{\cdot}7$;

$$\therefore\ \text{velocity} = 7{\cdot}97\sqrt{\frac{12 \times 5{\cdot}7 \times \frac{\pi}{4} \times 2g \times 2240}{182{\cdot}5}} = 1644 \text{ feet.}$$

These calculations are made for projectiles with heads of 1·5 diameters radius. For heads of 2 diameters radius there is a gain of from 10 to 5 per cent. This calculation is of course easily brought to a system and worked by logarithms, some of which are constant. Correct results are thus obtained.

The following objections may be used against General Inglis' system of calculating results. The assumption that the relation of t to d is known, confines the strict application to cases when "t" the thickness of armour is known, and the velocity only is required. If the velocity is known and t is required to be found, $\frac{t}{d}$ has to be assumed. It will be seen subsequently that this can be done roughly, but the great variation in the constant, or rather correction c, causes the error, liable to accompany a guess, to tell largely. Here lies the root of the principal objection to this formula; namely, that factors which should be constant if the formula was theoretically a perfect one, vary from 2·6 to 7·3. In other words, the formula is in itself so incorrect that it can only be made to give accurate results when corrections altering the answer about 200 per cent. are employed. This objection in no way applies to the diagram, which is admirable. This evil in the formula will be modified in a great degree by taking Fairbairn's original formula, and altering Inglis' table of factors or corrections c, to correspond to it.

Theoretically, this appears to be better, for the variation required in c to give correct results becomes so far reduced, that the formula appears to have a considerable measure of truth in it, and practically any error in assuming a relation of t to d tells comparatively little in the common problem when the thickness of plate is not given, but required to be found. This formula also agrees theoretically with the straight lines in Inglis' diagram.

It may be shown that in cases when the relation of t to D does not change, Inglis' formula is identical with that of Fairbairn. It is obvious that any number of (or, if desired, all) the constants in any expression may be embodied in some one symbol, and determined once for all by experiment. This factor being constant, combined with the variables, will satisfy all possible cases of perforation.

It may bring out the actual construction of the formulæ better to leave in them the constants which are identical in all, and express those that are peculiar to each as k_F, k_I.

Thus Fairbairn's is $$\frac{Wv^2}{2g} = \pi D \times t^2 \times k_F;$$

Inglis' $$\frac{Wv^2}{2g} = \frac{\pi}{4} D^2 \times t \times c.$$

And when t bears a *constant* relation to D, we may substitute t for one power of D, and express the factor required, together with c and $\frac{1}{4}$, under the symbol k_I, when the equation becomes—

$$\frac{Wv^2}{2g} = \pi D \times t^2 \times k_I;$$

which is identical with Fairbairn's, above, showing that k_I and k_F must be the same when determined by practice. So then when Inglis' formula requires no change in the factor c, it is identical with that of Fairbairn; but when a change is required and dealt with differently according to each formula, that of Fairbairn requires a much smaller variation in correction than that of Inglis.

The following are the factors, and their logarithms, for Fairbairn's formula corresponding to Inglis' table of factor c, that is, giving the same results :—

The value, then, of these factors varies from 13 to 9.

$\frac{t}{d}$	factor K.	logarithm of K.
·5	1·30	0·1139
·6	1·26	0·1004
·7	1·18	0·0719
·8	1·13	0·0511
·9	1·10	0·0414
1·0	1·05	0·0212
1·1	1·02	0·0086
1·2	1·00	0·0000
1·3	0·98	$\bar{1}{\cdot}9912$
1·4	0·96	$\bar{1}{\cdot}9845$
1·5	0·95	$\bar{1}{\cdot}9777$
1·6	0·94	$\bar{1}{\cdot}9731$
1·7	0·93	$\bar{1}{\cdot}9685$
1·8	0·92	$\bar{1}{\cdot}9638$
1·9	0·91	$\bar{1}{\cdot}9590$
2·0	0·91	$\bar{1}{\cdot}9590$

For calculating results on this system, using four-figure logarithms, the following are constant logs available for all questions :—

$$\log 2g \times 2240^{*} = 5{\cdot}1590;$$
$$\log \pi = 0{\cdot}4971.$$

Suppose the example above be taken when $t = 12$ ins., and $d = 7{\cdot}97$; that is, $\frac{t}{d} = 1{\cdot}5$, nearly, $\log c = \bar{1}{\cdot}9777$, $t = 12$, $d = 7{\cdot}97$, $w = 182{\cdot}5$.

Then,

$$\frac{Wv^2}{2g} = \pi d \times t^2 \times c$$

when v is required, becomes by transposing—

$$v = \sqrt{\frac{dt^2 \times \pi k \times 2g}{w}}$$

$$\begin{array}{rcl}
\log 7{\cdot}97 &=& 0{\cdot}9015,\\
2\log 12 &=& \begin{cases}1{\cdot}0792,\\ 1{\cdot}0792,\end{cases}\\
\log \pi &=& 0{\cdot}4971,\\
\log 2g &=& 5{\cdot}1590,\\
\log c &=& \bar{1}{\cdot}9777.\\
\hline
&& 8{\cdot}6937\\
\log 182{\cdot}5 &=& 2{\cdot}2613\\
\hline
&& 2)\ 6{\cdot}4324\\
\hline
\text{Ans.}\quad v = 1645. && 3{\cdot}2162.
\end{array}$$

This answer agrees with that obtained by General Inglis, above.

Next take a case when we do not know the thickness of the plate.

At Meppen, in March, 1882, Krupp fired a 15$^{\text{cm}}$ gun (5·87 in.), the shot weighed 112·44 lbs., the velocity about 1765 feet.

Suppose it is desired to find, in succession, E, the total *striking energy; e*, the *energy per inch circumference*, and t the *thickness of iron the shot is capable of perforating* :—

We have,

$$t = \sqrt{\frac{Wv^2}{2g} \times \frac{1}{\pi d} \times \frac{1}{K}}.$$

Obviously it is a simple and convenient thing to use a process giving E, e and t in succession.

---

* The factor 2240 is employed to bring the weight of the shot in lbs. to foot-tons; g is taken as 32·19.

log W, that is log 112·4 =		2·0507
2 log V, that is 2 log 1765 =		3·2467 3·2467
		8·5441
log (2240 × g)		5·1590
(E) striking energy $=\left(\frac{Wv^2}{2g}\right)$ =	2428	3·3851
log (π × 5·87) =		1·2657
(e) work per inch circumference $=\left(\frac{Wv^2}{2g}\times\frac{1}{\pi d}\right)$ =	131·4	2·1194
log c =		$\bar{1}\cdot9685$
inches		2·1509
(t) thickness that may be perforated =	11·90	1·0755

log 5·87 = 0·7686
log π = 0 4971
1·2657
[1] log c = $\bar{1}\cdot9685$

Maitland has a formula $K = \cdot001V - \cdot14$ when V is greater than 700, and another $K = \cdot0008V$ when V is less than 700;

Maitland's $V = \sqrt{\frac{\log^{-1} 5\cdot5904 E}{D^3}}$. E being the striking energy $\frac{Wv^2}{2g}$.

This may be compared with Fairbairn's formula easily by writing it as follows:—

$t = DK$ as noticed before, K being t in calibres;

$$= D \times \left\{ \cdot001 \sqrt{\frac{\log^{-1} 5\cdot5904}{D^3} \times \frac{Wv^2}{2g}} - \cdot14 \right\}$$

and taking $D \times \cdot001$ inside the root and then cancelling D^2 in numerator and denominator.

$$t = \sqrt{\frac{Wv^2}{2g} \times \cdot000{,}001 \frac{\log^{-1} 5\cdot5904}{D}} - \cdot14D;$$

and, writing K_M for the constant $\cdot000{,}001 \log^{-1} 5\cdot5904$,

$$t = \sqrt{\frac{Wv^2}{2g} \times \frac{1}{D} \times K_M} - \cdot14D,$$

which is almost identical with Fairbairn's in the form for perforation, putting K_F and K_M for Fairbairn's and Maitland's constants;

namely, $$t = \sqrt{\frac{Wv^2}{2g} \times \frac{1}{\pi D} \times K_F}.$$

---

[1] c is taken on the assumption that each complete 1000 feet velocity represents a calibre penetration. Thus, over 1000 feet is assumed equal to the perforation of 1 calibre, over 1500 feet equal to 1·5 calibres, and so on. This assumption is explained hereafter, and is sufficiently near to the truth for the purpose. Thus for 1765, if 1·7 calibres be taken on table p. 27, we have $\bar{1}\cdot9685$.

If the constant K_M were modified to enable π to be combined with D, Fairbairn's and Maitland's would only differ in the fact that Maitland makes a constant small correction in terms of the shot's diameter, and this disappears in his second equation when V is less than 700.

The formulæ of Inglis and Maitland give nearly the same results. Fairbairn's, as corrected above, does the same, and appears simple and good. It has a considerable measure of truth, but is also empirical in a measure. If theoretically correct, it would not require a change of the factor K, which would then be really a constant. Captain A. Noble has worked out a modification of Fairbairn's formula. On the other hand, Major English, R.E., has a formula, based on a very searching investigation of conditions, but which cannot here be discussed.[1]

There are formulæ used abroad which, like that of Inglis', treat the resistance of the plate as proportional to the cross section of the shot, not to its circumference. This may be true, as noticed in preceding chapter, in an early stage of penetration, but after the plate begins to tear open in a cross at the back, it appears as if the remainder of the work was proportional to the length of these lines, or rents, which are functions of d, the shot's diameter, not of d^2 as in the case of the area. For a rough approximation there is a rule of thumb, which may be noted as very easily applied, and the circumstances under which it is liable to any considerable error, and also the probable extent of the error may be generally foreseen, as it is based on a formula which is true if two assumptions are made,[2] assumptions which are seldom grossly wrong, and are fairly near the truth in the most important cases, that is, with projectiles with fairly high sectional density, fired at high velocities; for instance, when fired from new type guns. These assumptions are (1) that Fairbairn's original formula, as given above, is correct. (2) that all projectiles have the same proportion of weight to diameter (or "sectional density"), so that $\frac{W}{d^3}$ is in all cases the same. Then taking Fairbairn's formula, viz.,—

$$\frac{Wv^2}{2g} = \pi d \times t^2 \times K_1$$

or

$$t^2 = \frac{Wv^2}{2g} \times \frac{1}{\pi d} \times \frac{1}{K_1};$$

writing $K_2 d^3$ for W, which amounts to assuming that the weight is proportionate to the cube of the diameter, which is a true assumption in projectiles of the same sectional density;

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[1] Professor Greenhill kindly went into this question with me, and concluded that it was better not to use Major English's formula.

[2] The author has generally had the credit given him for this rule, *see* Very, "Development of Armour," p. 580, and Mackinlay's "Text Book on Gunnery," p. 142. The fact is, that the author on examining the results obtained by Inglis' Committee, thought he discovered the law, and then found the mathematical proof herewith. He afterwards found that both Inglis and Maitland had, in a measure, seen the law; General Inglis had enunciated it for three cases, roughly, in his paper on "Armoured Defences," read 1880, p. 10. The author trusts that the proof herewith justifies confidence, which an apparent law in one series of trials would not deserve, and he put it forward boldly, and applied it generally in his paper of October, 1881. He, now, however, thinks that both Inglis and Maitland must have perceived the law before he even saw the results on which it is based.

$$t^2 = K_2 \frac{d^3 \times v^2}{2g \times \pi d \times K_1},$$

writing K_3 for all the constants, that is for $\frac{K_2}{2g \times \pi \times K_1}$ and cancelling d above and below—

$$t^2 = d^2 \times v^2 \times K_3;$$

and taking the square root,

$$t = d\,v\,\sqrt{K_3}.$$

That is, the thickness perforated is equal to the calibre or diameter of shot multiplied by the velocity in feet and by some constant $\sqrt{K_3}$; and this constant turns out to be nearly $\frac{1}{1000}$[1]; so that supposing this to be true, the thickness of iron that may be perforated by a shot is very easily found by multiplying the calibre by the number of thousand feet striking velocity. Thus, an 8-inch shot to perforate 8 inches would require 1000 feet velocity. To perforate 12 inches it would require 1500 feet velocity, each 1000 feet velocity giving 1 calibre perforation. Suppose then with the 26-ton B.L. gun 10·4-in. calibre, the shot has a muzzle velocity of 2080 feet, it ought to perforate $\frac{2080 \times 10{\cdot}4}{1000} = 21{\cdot}6$ inches. This happens to be exactly the perforation given by Inglis' diagram. For 1500 feet velocity the rule would give 15·6, and the diagram 15·1 inches. The rule of thumb being very near the truth when $v = 2000$ feet, and $\frac{W}{d^3} = 0{\cdot}41$ about.

The table herewith shows the amount of error occurring in different cases from the use of the rule, supposing Inglis' diagram to be correct. It will be seen that considerable error exists when the projectile is light, as in the case of certain Armstrong guns, where $\frac{W}{d^3} = 0{\cdot}34$ or 0·37. Projectiles for the future, on the other hand, are likely to have high sectional density. An Officer, however, would surely know the general character of a gun that he was firing, and make allowance for a low velocity, or specially short light, or specially heavy projectile. As a high limit, however, the rule may be generally safely used. That is to say, it may be safely assumed that a shot will scarcely ever perforate, on service, *more* than would be given by the rule. With wrought-iron it is to be remembered that partial penetration does armour no appreciable injury, for the shot generally only makes a hole to a certain depth, and plugs it up, leaving the surrounding parts of the shield and bolts very little injured. *It is very important then not to waste shot in firing at wrought-iron beyond the power of the gun.* Consequently, the following rule is suggested; *it is useless to fire at wrought-iron armour unless the shot has at least 1000 feet striking velocity for each calibre in the thickness of the armour.*

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[1] Agreeing with the ·001 of Maitland.

The measure of accuracy of the results given by the Rule of Thumb with most types of guns now in use may be seen in the following table, which, however, does not include the newest designs:—

TABLE SHOWING HOW FAR THE RESULTS GIVEN BY THE RULE OF THUMB AGREE WITH THOSE OF INGLIS' DIAGRAM.

NATURE OF GUN.	Calibre.	$\frac{W}{D^3}$.	At Maximum or Muzzle Velocity.				Penetration at 1500 ft. Velocity.			Penetration at 1000 ft. Velocity.		
			Velocity.	Penetration.		Difference, Rule of Thumb − Diagram.	By Rule of Thumb.	By Diagram.	Difference.	By Rule of Thumb.	By Diagram.	Difference.
				By Rule of Thumb.	By Diagram.							
100-ton Armstrong B.L.	17·72	·40	1500	26·6	25·3	+1·3	26·6	25·3	+1·3	17·7	16·1	+1·6
" " M.L.	17·72	·36	1735	30·7	28·1	+2·6	26·6	24·0	+2·6	17·7	15·3	+2·4
71-ton Krupp B.L....	15·75	·44	1653	26·2	26·5	−0·3	23·6	23·8	−0·2	15·8	15·2	+0·6
80-ton M.L.	16·0	·42	1613	25·8	25·2	+0·6	24·0	23·3	+0·7	16·0	14·6	+1·4
51-ton Krupp B.L....	13·98	·42	1650	23·1	23·0	+0·1	21·0	20·7	+0·3	14·0	13·1	+0·9
46-ton French B.L.	13·38	·39	1640	21·9	20·9	+1·0	20·1	19·0	+1·1	13·4	—	—
38-ton M.L.	12·5	·42	1475	18·4	17·9	+0·5	—	—	—	12·5	11·7	+0·8
38-ton Krupp B.L....	12·01	·43	1650	19·8	19·7	+0·1	18·0	17·8	+0·2	12·0	11·3	+0·7
43-ton B.L.	12·0	·42	2005	24·1	23·9	+0·2	18·0	17·5	+0·5	12·0	11·1	+0·9
25-ton M.L.	11·0	·41	1410	15·5	15·0	+0·5	—	—	—	11·0	10·3	+0·7
26-ton B.L.	10·4	·41	2080	21·6	21·6	0·0	15·6	15·1	+0·5	10·4	—	—
25-ton Armstrong B.L....	10·0	·40	2012	20·1	20·0	+0·1	15·0	14·5	+0·5	10·0	—	—
18-ton M.L.	10·0	·42	1515	15·2	14·7	+0·5	15·0	14·5	+0·5	10·0	9·3	+0·7
17·7-ton Krupp B.L.	9·45	·42	1890	17·9	18·1	−0·2	14·2	14·0	+0·2	9·5	8·9	+0·6
18-ton B.L.	9·2	·41	2000	18·4	18·4	0·0	13·8	13·4	+0·4	9·2	8·4	+0·8
18-ton Armstrong B.L....	9·0	·34	2250	20·3	19·0	+1·3	13·5	12·1	+1·4	9·0	—	—
12-ton M.L.	9·0	·35	1540	13·9	12·4	+1·5	13·5	12·1	+1·4	9·0	7·7	+1·3
11½-ton B.L.	8·0	·36	2040	16·3	14·9	+1·4	12·0	10·8	+1·2	8·0	6·9	+1·1
3·9-ton Krupp B.L.	5·86	·55	1664	9·7	11·5	−1·8	8·8	10·2	−1·4	5·9	6·6	−0·7
5-ton French B.L.	6·28	·40	1738	10·9	10·7	+0·2	9·4	9·1	+0·3	6·3	5·7	+0·6
4-ton Armstrong B.L....	6·0	·37	1960	11·8	11·2	+0·6	9·0	8·3	+0·7	6·0	5·3	+0·7

The Rule of Thumb gives the best results when V = 2000 feet about, and $\frac{W}{D^3} = \cdot 41$ about.

In the new designs, where $\frac{W}{D^3}$ exceeds 0·5, the result obtained will be considerably in excess of that found by the Rule of Thumb, but practically, on service, it would seldom be possible to obtain greater perforation than would be indicated by the Rule of Thumb.

Thus, with a 12-inch gun, it would be useless to fire at 12 inches of armour (1 calibre) unless the shot would strike with over 1000 feet velocity. 15 inches of armour (1¼ calibres) would require over 1¼ thousand, that is, over 1250 feet. To sum up shortly with one or two practical directions.

Practical Directions.

To estimate quickly the power of a gun in *perforating wrought-iron armour* with service guns and projectiles,[1] consult Inglis' diagram, or Maitland's if preferred. Maitland's may be used in other cases.

Failing diagrams, take the calibre of the gun as a measure, and reckon that at least 1000 feet velocity is required for each calibre in the thickness of the armour to be perforated. In old type guns, with light shot, considerably more velocity may be required.

For deliberate calculation, when stored-up work as well as perforation is required, Fairbairn's formula with the corrections for *K*, given hereafter, is recommended. In doing this, it may be observed that the formulæ[2] used at Gavre and in Italy closely resemble it in form; Krupp's formula, only, assuming the resistance to be proportional to area of hole perforated. To facilitate calculation for those who may only occasionally perform it, an example is worked out on Fairbairn's system as here recommended, and all the necessary data for any calculation given, that is, a table of four-figure logs, and a table of corrections of *K* are supplied with it.

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[1] If the charge as well as the projectile is that given on Inglis' diagram, the perforation at any range may be at once read off. If the charge is not that given on the diagram, the velocity at any range will not agree with that given there, and it will be necessary to know the striking velocity and to read off the perforation corresponding to that velocity, though found at a different range from that in question.

[2] The Gavre formula is $V_m = 1600 t_d \sqrt[0\cdot7]{\frac{D_d}{W_k}}$ in iron; in wood $V_m = 95 t_d \sqrt{\frac{D_d}{W_k}}$, where t_d = thickness in decimeters; D_d = diameter in decimetres; W_k = weight in kilogrammes; and V_m = velocity in metres.

The Italian formula is $t = \sqrt[1\cdot4]{\frac{Wv^2}{2g} \cdot \frac{1}{\pi D} \cdot \frac{1}{4\cdot154}}$. Krupp's is $\frac{Wv^2}{2g} \times \frac{1}{A_c} = \frac{t_c}{10} \sqrt[3]{\frac{t_c}{D_c}}$; where A_c = area of cross section of projectile in centimetres, D_c diameter in centimetres, and t thickness in centimetres.

The French formula may be written, of course, $t = vk \sqrt[0\cdot7]{\frac{W}{D}}$, which differs only from Fairbairn's by k the constants, and root being different.—*vide* "Development of Armour"; Very, p. 581.

FOUR-FIGURE LOGARITHMS.

No.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	6	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	7	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

Four-Figure Logarithms—(*Continued*).

No.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	3	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

Example.—At Spezia, on November 16th, 1882, the first projectile fired from the 100-ton M.L. gun struck Cammell's plate with a striking velocity of 1219 feet per second; its weight was 2000 lbs., and its diameter 17·64 inches.

Table of logs of correction K.	
v in feet.[2]	Log of K.
500	0·1139
600	0·1004
700	0·0719
800	0·0511
900	0·0414
1000	0·0212
1100	0·0086
1200	0·0000
1300	$\bar{1}$·9912
1400	$\bar{1}$·9845
1500	$\bar{1}$·9777
1600	$\bar{1}$·9731
1700	$\bar{1}$·9685
1800	$\bar{1}$·9633
1900	$\bar{1}$·9590
2000	$\bar{1}$·9590

The formula is $t = \sqrt{\frac{Wv^2}{2g} \times \frac{1}{\pi D} \times \frac{1}{K}}$;

that is,

$$\log t = \tfrac{1}{2}(\log W + 2\log v - \log 2g - \log \pi D - \log K).$$

Here $W = 2000$, $v = 1219$, $D = 17·64$.

The constant [1] $\log(2g \times 2240) = 5·1590$ Log 2000 = 3·3010

Constant $\log \pi = 0·4971$ 2 log 1219 = $\begin{cases} 3·0859 \\ 3·0859 \end{cases}$

log 17·64 = 1·2465. 9·4728

Here, adding these, $\log \pi D = 1·7436$. $\log 2g =$ 5·1590

E, striking energy $\frac{Wv^2}{2g} = 20600$ ft.-tons 4·3138

$\log \pi D = 1·7436$

e, energy per inch circumference $\frac{Wv^2}{2g} \times \frac{1}{\pi D} = 371·7$ ft.-tons 2·5702

[3] log K for 1200 taken from table = 0·0000

2)2·5702

t, thickness of wrought-iron to be perforated 19·26 1·2851

For plate-upon-plate in 2 layers t should be multiplied by $\frac{25}{24}$.
″ ″ 3 layers t ″ ″ $\frac{10}{9}$.

The rule of thumb here gives 17·6 × 1·2 = 21·12 ins., which is an unusually bad result; this gun being the one for which this rule gives the largest error shown on the table on p. 31.

Hard Armour.

In compound or steel-faced armour, actual perforation has occasionally been obtained;[4] occasionally also a steel shot has set up and driven a large disc out of a compound plate, which action may partake of the character of perforation, and its diameter may bear some relation to that of the projectile. Most compound and solid steel shields, however, and all chilled iron shields must be destroyed by fracture, the shot's point penetrating only to a certain depth, often quite an insignificant one. Here, then, fracture is caused by a blow delivered, as it were, on an ogival-pointed wedge which splits the shield asunder. This action differs widely from perforation; for while in both cases the stored-up work or energy is the motive power, in *perforation* the thickness perforated depends inversely on the size of the hole or diameter of shot; whereas in destruction by fracture, the point only of the shot enters the plate, and its diameter can scarcely enter into the question. As has been before said, when all other conditions are the same, it may be supposed that fracture effected on any given plate may be simply proportional to the stored-up work; but this, if a fact, is of little use to us, for other conditions will very seldom be the same as that of some known example. It may apply to the case of different guns attacking the same shield if their projectiles are of the same kind, differing only in dimensions or weight, but even then, unless the shot hold together on impact, which at present hardly ever occurs against hard armour, there are uncertain elements. A higher striking velocity may cause one projectile to break up more abruptly, and deliver less of its energy on the shield usefully than another with a lower striking velocity, also the mechanical action of the breaking up of projectile can hardly fail to be affected in some degree by its diameter, and hence even here the problem may be more difficult than that of perforation. Directly changes are made in the shield the problem is altogether beyond the present powers of artillerists to grapple with, as may be seen easily.

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[1] g is multiplied by 2240 to bring lbs. to tons, the shot's weight being given in lbs., and the energy required in foot-tons.

[2] The velocity is here substituted for the relation $\frac{t}{D}$ in this column, being approximately proportional to it, as stated in Note 1, p. 28, and explained on pp. 29 and 30.

[3] As the striking velocity generally exceeds 1200 feet, the correction for K generally consists in subtracting a log with a minus 1 before it, thus slightly increasing the figures.

[4] *Vide* Palliser improved shot trials, &c.

The method adopted of matching a shot against a steel-faced or steel plate has generally been to give the projectile sufficient energy to perforate wrought-iron of the same thickness, or else 25 per cent. more thickness than the compound or steel plate attacked.

The table following shows this to have been the method followed at Shoeburyness, at Spezia, and at St. Petersburg in the experiments referred to. In each case, except the last,[1] the power of the shot was calculated evidently on the basis of perforation; yet, as may be seen by referring to the accounts of the experiments (Chap. VII.), the plates were destroyed by fracture. That perforating power was the measure used is made apparent by comparing columns 5 and 6 together, when it will be seen that a low and high test appear to be framed in each case. On the low test, the shot had the energy necessary to perforate a thickness of wrought-iron equal to that of the compound plate attacked, and for the high test the shot had energy sufficient to perforate a wrought-iron plate of 24 to 33 per cent. greater thickness than the compound plate attacked. It is easy to see that this is a totally wrong principle,[2] but it is not at all so easy to propose a better one.

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[1] The last was a totally different kind of experiment, to be described hereafter in Chapter VII.

[2] The author has illustrated the different actions of perforation and smashing at Woolwich, the United Service Institution, and the Iron and Steel Institute by means of a dropping apparatus, or pile-driver, consisting of a frame in which a weight fell, driving punches or bullets inserted in it into soft or hard substances such as admitted of perforation, or yielded by fracture respectively. Slabs of millboard and hard tiles were found to answer fairly well. Steel punches—one inch, half-an-inch, and a quarter-of-an-inch in diameter—were employed, with ogival heads corresponding to those of service projectiles. As the velocity was that of the falling weight, the striking energy $\frac{Wv^2}{2g}$ was equal to WH (weight × height), and Fairbairn's equation might be written $WH = \pi d\, t^2 k$. Nothing could be much more simple than this, and the effect of one element on another could be easily seen by trial, leaving all other conditions constant. Thus in perforation, it could be shown that to perforate a given slab the height of fall must be nearly in direct proportion to the diameter of the shot or punch. When the $\frac{1}{4}$-inch required 17 inches fall, the inch required 60. To agree exactly with the equation the three punches should require 15, 30, and 60 inches fall for the same slab, and the more nearly the work was localized and brought to clean punching, the more nearly was this the case. With the hard brick or tile, on the other hand, fracture was caused

Table showing that in recent experiments shots have been matched against compound plates according to their calculated powers of perforation (*vide* Columns 5 and 6), not according to their smashing powers, for which Column 9 is suggested as a measure.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Date and Place of Trial.	Gun.	Weight of Shot.	Striking Velocity.	Thickness of Compound Plate.	Calculated Perforation of Shot. Inches of Iron.	Total Energy.	Weight of Plate.	Energy per Ton of Plate.	Remarks on Effects.
		lbs.	feet.	ins.		ft.-tons.	tons.		
July 1, 1880, Shoeburyness.	38-ton	828	1504	18	18·7	12,980	24	541	Face cracks and dents only.
1882, Shoeburyness.	43-ton	708·5	1870	18	22·3	17,180	...	...	Plate completely broken up.
November, 1882, Spezia	100-ton	2000	1219	18·9	19·3	20,600	31·5	654	Large portion of corner broken away.
			1565	18·9	25·2	33,960	31·5	1046	Plate broken to pieces.
November, 1882, and March, 1883, Ochta, St. Petersburg	11-in. B.L.	553·5	1167	12	12·2	5,228	12·25	427	Portion of face detached and face cracks produced.
			1506	12	16·3	8,704	12·25	711	
Sept. 10, 1883, Shoeburyness.	80-ton	1700	1599	12	25·3	30,140	10·5	2870	Plate bent and cracked severely.

Both in England and in Germany a check has been attempted by treating the question in the opposite way, that is to say, by considering that the hard armour is fractured by delivering a shock through its mass that severs it along lines of least resistance. Thus, if the striking energy of the shot be divided by the weight of the armour in tons, the quotient gives the number of foot-tons energy delivered on every ton of armour, *vide* column 9 in table. This, however, is clearly liable to be as far wrong as the perforation system of calculation. There must be some limit as to the distance of the mass from the point of impact that could be thus dealt with. Two long narrow plates, for example, might be taken, one double the length the other. Both would snap across, and with nearly the same blow probably,[1] yet the mass of one being double that of the other, the blind application of the rule just given would indicate that one would absorb twice the shock of the other before fracture occurred.

The question of fracture is a difficult one. It has been said to be altogether beyond mathematical calculation. It must, however, follow

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by a given weight falling from a given height without regard to the size of the punch which was employed as a striker. For perforation, then, the inch punch required four times the fall of the ¼-inch (when both were driven by the same weight), because it made a hole of four times the diameter, but for fracture, it required only the same fall, for its point only came in contact and split the brick by its striking energy, without reference to the diameter of the punch. A toy of this kind is only good for illustration, but the effects are simple and striking, and the holes in the millboard so closely resembled perforations through iron armour, that a photograph of one can hardly be detected from that of the other. Admiral Fishbourne, it appears, suggested that a pile-driver might be used for illustration, many years ago, but the author had never heard of it.

[1] Theoretically the long one might break the more easily of the two.

certain laws if uniformity of quality could be secured, for even steel is not really capricious. The elements certainly are troublesome ones. As to dimensions, the minimum cross measurement is the line of most probable fracture, but bolt-holes and other features have their influence. Cracking itself is a complicated action. Clearly the first half of a crack represents much more work than the completion of it, consequently an increase in width of plate would not probably give a plate a proportional increase in resisting power. It is suggested that the subject might be approached on a small scale,[1] that steel bullets might be fired against small slabs of steel and chilled iron. These slabs should be sufficiently long to ensure a line of least resistance in one direction, which would probably depend on its actual dimensions; a disc or any plate where the direction of the line of least resistance might probably be determined by a flaw would be the worst kind to employ. By firing at very great numbers of small plates with all the conditions fixed, except the one at the moment under investigation, it is probable that something might be learned of the laws of fracture under impact. In the meantime, little can be said definitely about it, beyond the elementary but important fact that effect is not proportional to the shot's perforation, but much more nearly to its total energy, a consideration that may actually effect the selection of the guns employed against hard shields on service;[2] if, however, armour should in the long run be made hard enough to resist perforation proper, that is, perforation without breaking up the armour, it follows that the destructive powers of guns will depend not upon their power of perforation but upon the stored-up work or energy. The value of a gun may generally, therefore, be estimated on the measure used by Krupp, that is, the energy per ton of gun. New type guns will not then benefit by the fact that the reduced diameter of the projectile demands a smaller hole in the plate; but they will benefit by the increase in total striking energy. For example, the new 63-ton gun of 13·5-in. calibre of 1884[3] has a velocity of 2050 feet and a perforation at the muzzle of about 30 inches of iron. This will seldom apply, for it will seldom have to fire at anything approaching 30 inches of iron; the nearest approach perhaps may be found in very soft steel. The projectile has, however, a total energy at the muzzle of about 36,350 foot-tons. This will represent its total smashing power against hard armour. This is about 577 foot-tons per ton of gun, which represents the value of the gun as an investment in artillery power. If this be compared with the energy per ton of the 38-ton gun, which was 360 foot-tons, the extent of the Artillery improvements in the construction of guns and burning of powder will be appreciated.

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[1] Probably few are aware of how completely Fairbairn's formula was worked out by him, with punches, on a small scale. It seems only reasonable to apply tests on a small scale to the much more difficult question of smashing.

[2] For example, old type guns, such as the 25-ton guns, carried on board many of our vessels might be found in the same attacking force as new type guns firing shot of smaller calibre and less energy but greater penetrating power. The former guns would give the better results against chilled iron shields, and the latter against wrought-iron.

[3] *Vide* "Heavy Guns of 1884," by Colonel Maitland, "U.S. Proceedings," 1884. The high sectional density of the projectile makes the Rule of Thumb work very badly for this gun, giving under 28 inches perforation: 2·05 × 13·5 = 27·7 inches.

CHAPTER IV.

Further Experiments with Soft Armour.

Prussian trials.

In 1868,[1] a Prussian trial took place between the English 9-inch and Krupp's 24^{cm} (9·27-inch) guns, against 6, 7 and 8-inch iron plates with backing and skin, when the English gun maintained a decided advantage. In July and August of the same year, the Krupp gun and projectiles had been so far improved that they beat the English ones; the projectiles especially were thought to be good.

Russian *Hercules*.

In August, 1869,[2] an 11-inch Krupp gun was fired in Russia against a target representing, very nearly, H.M.S. *Hercules* armour at the water-line amidships. It consisted of 9 and 6-inch plates on a structure consisting of 39 inches of backing, consisting of 36 inches of wood and angle-iron, and 2 intermediate iron plates, each 1 inch thick, and an iron skin 1 inch thick. The projectiles, which were of steel, weighing 496 lbs., perforated the thickest part of this structure easily at 467 yards, passing on up the range. Capt. (now Colonel) W. H. Noble estimated their striking velocity at 1247 feet, and energy per inch circumference at 155 foot-tons. There is therefore nothing remarkable in the perforation of the target. The projectiles, however, must have been excellent, and foreshadowed what Krupp's steel projectiles would be.

"No. 31" Target.

On March 3, 1870, a structure consisting of three 5-inch plates with iron concrete between, termed "No. 31" target, was tested by 12-inch guns, and others of smaller calibre.[3]

Filled shells exploded by impact.

On May 12, 1870,[4] an experiment was made to test the liability of filled shell to explode when struck by projectiles after passing through armour. The *Warrior* target was employed, and shells placed behind it in various ways were struck by 9-inch projectiles after perforating the armour. It was concluded, after this trial, that fuzed shells are no more liable to explosion than plugged filled shells, also that explosion may generally be limited to the shell actually struck, if live and empty shells are placed alternately in the interior of the ship. It may here be noticed that the impact of the penetrating projectile, whether shot or shell, generally explodes any filled shell which it actually strikes.

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[1] *Vide* Very's "Development of Armour, p. 441." For all American experiments and many foreign ones not here given, the reader cannot do better than consult Very's able work.

[2] *Vide* D. of A. "Proceedings," Vol. VIII., p. 53; also Very's "Development of armour," p. 437. Very gives the range as 1200 yards.

[3] *Vide* D. of A. "Proceedings," Vol. VIII., pp. 47 and 206.

[4] *Vide* D. of A. "Proceedings," Vol. VIII., p. 121.

Ships Decks Targets.

Deck targets "No. 32" under Mortar fire.

In 1870,[1] very important experiments were commenced by the Admiralty, to test the resisting power of ships decks. A target was erected at Shoeburyness (known as "No. 32") representing a ship's deck. In order to prevent the waste of time and ammunition, arising from the inaccuracy of vertical fire, the target, instead of being laid horizontally, was placed in a vertical plane, and it was attacked by horizontal fire with projectiles with reduced charges, giving striking velocities such as they might have in falling on a deck. The target was as follows:—Iron deck beams, 10 inches deep, of T section, and running across the greatest breadth of the deck at 2 feet interval, were covered with 6 inches of deck material all over. In one portion (10 feet × 10 feet) this 6 inches was made up of 1½ inches of iron (in two ¾-inch plates) and 4½ inches of fir, and in another portion (10 feet × 10 feet) it was made up of 1 inch of iron (in two ½-inch plates) and 5 inches of fir.

A 13-inch L. S. mortar was fired at this, on April 7, 1870, from 20 yards range, striking at angle of 60° with the target, with a shell filled with sand; 7 lbs. of L. G. powder, giving 514 feet striking velocity, and 379 foot-tons energy (9·4 foot-tons per inch circumference), two shells thus fired passed through both portions of the deck. With a 3½ lbs. charge and 327 feet striking velocity, and 154 foot-tons striking energy, and 3·8 foot-tons per inch circumference, the shell passed through the inch iron portion, but rebounded on the inch-and-a-half plates, cracking them sufficiently to show daylight through. The 7 lbs. charge, was calculated to give the striking velocity of a shell fired with 20 lbs. from a S. S. mortar at 45° elevation. The 3½ lb. charge was intended to test the actual resistance of the plate. The iron deck beams were broken in the inch portion, but the first shell passed between them in the 1½-inch portion.

Deck targets under gun fire.

On June 14 and 15, 1870, and May 3 and 5, 1871,[2] the 9-inch M.L. gun was fired at the deck target at 100 yards range. The target had been repaired and laid on the sand; the angle of incidence of the projectiles was given by raising or lowering one end of the target. The sides of the vessel were represented by ½-inch plates, 2 feet 6 inches deep, worked on to projecting edge of deck plates, with angle-iron 3 inches × 3 inches × $\frac{1}{2}$ inch, and connected with each deck beam by a triangular web piece. The iron work was fastened with 1-inch rivets. The wood was secured with four $\frac{7}{8}$-inch galvanized iron bolts to each plank. The target was supported on wood piles, with the deck beams parallel to the line of fire. The 9-inch M. L. gun was fired with a 43 lbs. charge, and Palliser shell 250 lbs. weight, containing 5 lbs. of powder. At 15°, and at 10°, the shell, which had a striking velocity of 1328 feet, a total energy of 3060 foot-tons, or 109 per inch circumference, passed through, tearing the decks much; at 8° the shells deflected without exploding, still, however, tearing the deck considerably.

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[1] D. of A. "Proceedings," Vol. VIII., p. 123, and Vol. IX. p. 93.

[2] D. of A. "Proceedings," Vol. VIII., p. 209, and Vol. IX., p. 93.

"No. 32 A" target.

On June 19, 20, and 21, and on July 16, 1872,[1] another deck target (32A) was fired at, representing upper and breastwork decks of H.M.S. *Thunderer*. This target measured 24 feet × 14 feet, the left half representing the upper deck, the right half the breastwork deck. The upper deck consisted of 4-inch oak fastened with $\frac{7}{8}$-inch screw bolts to three thicknesses of 1-inch iron plating. The latter were secured with $1\frac{1}{8}$-inch rivets to iron beams 4 feet apart, 11 inches deep × $\frac{1}{2}$-inch thickness, and two angle-irons 3 inches × 3 inches × $\frac{1}{2}$-inch. The breastwork deck consisted of $3\frac{1}{2}$ inches of oak planking, fastened with $\frac{3}{4}$-inch screw bolts to two thicknesses of 1-inch iron plating. The latter were secured with $1\frac{1}{8}$-inch rivets to T iron beams 4 feet apart, 8 inches deep, × $\frac{1}{2}$-inch in thickness.

The 9-inch M. L. gun was fired with 50 lbs. charge, and Palliser shell containing 4 lb. 4 oz. bursting charge, thus weighing about $246\frac{1}{2}$ lbs. The striking energy was 3396 foot-tons total, or 121 per inch circumference. At 8° incidence the shell deflected on off upper deck and breastwork deck without exploding, cracking and bulging deck, and tearing up wood. A flat-headed shell behaved in a nearly similar way. 10-inch Palliser shells, each weighing, with bursting charge of 5 lb. 12 oz., in all about $396\frac{3}{4}$ lbs., and having a striking energy of 5055 foot-tons total, or 162 per inch circumference, deflected at 8° without bursting, twice, and once burst. At 10° one shell burst; of one it could not be certainly said if it burst or not.

Targets below water.

On November 17 and 27, December 21, 1871,[2] and January 9, 1872, firing was conducted against targets, placed below water at angles of depression of from $6\frac{1}{2}°$ to 12°, with ogival and flat-headed shot. The ogival Palliser projectiles ricochetted on the water at angles less than 11°, but at greater angles remained under water. Flat-headed shot remained under, at about $8\frac{1}{2}°$ depression.

35-ton gun fired at "No. 33" target.

On June 20, 1872, the 35-ton gun of 12 inches calibre was fired against a target, known as "No. 33," at Shoeburyness,[3] which consisted of 8 inches of iron, then 6 inches backing, 5 inches iron, 6 inches wood, and 1½ inches of iron skin. This structure not being a match for the gun, was strengthened by an additional plate of 4 inches of iron, which however was from some cause laid on with 5-inch timbers round under its edges only, leaving a 5-inch space between itself and the front of "No. 33" proper. There was reason to think the target itself was not up to the proper standard for such a structure, owing to the metal being inferior, and the experiment would not be worth notice had it not been for the air space and its possible influence on the results. A Palliser shell with bursting charge of 9 lbs., weighing 694 lbs., was fired with a striking velocity of 1296 feet, a total energy of 8090 foot-tons, and 216 foot-tons per inch circumference. It burst, the head penetrating to 35·7 inches depth, leaving a hole in front plate of from 12·1 to 12·5 inches diameter. A girder and some rivets were broken and started in rear. The top edge of front 4-inch plate was thrown back against the target proper, the supporting timbers having been dislodged so that the second shot would find greatly diminished air space. This was fired without bursting charge with about the same striking energy as the preceding one; it drove its head completely through the target, leaving the body lodged in the 5-inch plate. The base was left behind, not entering the plate at all. The perforation is not much worth calculating, owing to the uncertainty as to the character of the target, but it is perhaps rather more than could have been expected. The most interesting feature is the fact of the projectile perforating the plate when fired as a shot, and failing to do so as a shell. This must be attributed mainly to the circumstance that the bursting interferes with penetration in thick armour, because the powder acts and blows away part of the shell before it has done its work fully. Also it is possible that the larger air space may have contributed to the greater shattering of the first shell.

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[1] D. of A. "Proceedings," Vol. IX., p. 249, and Vol. X., p. 170.

[2] D. of A. "Proceedings," Vol. X., p. 25.

[3] Reported in "Engineer," by Author, June 28, 1872. D. of A. "Proceedings," Vol. X., p. 173. No. 33 was perforated by 11-inch projectile, September 9, 1872. D. of A. "Proceedings," Vol. X., p. 293. Sandwich targets, known as "34" and "35," with 8 ins. iron, 9 ins. wood, 5 ins. iron, and 5 ins. wood, *i.e.*, 13 ins. iron besides skin, were perforated by 35-ton gun with e=182.

Finspong projectiles.

On August 21, 1871,[1] at Shoeburyness, two Finspong 9-inch chilled iron projectiles, fired at Shoeburyness, rebounded from a Millwall iron shield without breaking, further than a few cracks being made at the stud holes.

The Glatton Turret Experiments.

***Glatton* turret experiment.**

On July 5, 1872, at Portland,[2] took place the notable experiment on the turret of H.M.S. *Glatton*. The object of this was to ascertain whether the turret could be disabled either by the revolving gear being put out of order, or the structure itself being so far distorted as to interfere with the turning of the turret, or lastly, if the turret might be riveted or wedged to the glacis by the entrance of a shot at the junction of turret wall and glacis plate. The *Hotspur* was drawn up at 200 yards distance, and fired two effective rounds from a 12-inch 25-ton gun, at the *Glatton* turret. The fact that the trial was one on contortion or racking, and not one on penetration, must be clearly kept in view, and the construction of the turret should be understood. It may be seen in Fig. 1, herewith, that a single layer of armour plates,

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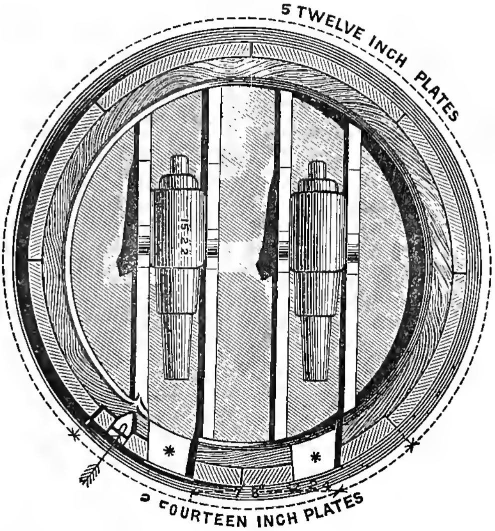
[1] D. of A. "Proceedings," Vol. IX., p. 174.

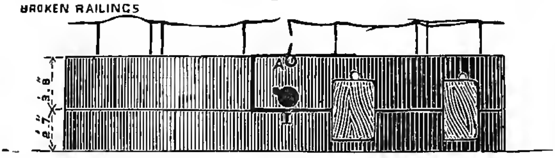
[2] D. of A. "Proceedings," Vol. X., p. 175, Authors Report, "Engineer," July 12, 1872, and also in "Naval Science," January, 1873, p. 32.

Fig. 1.



each extending for one eighth of the circumference, surrounds a layer of wood, with a skin and second or smaller skin inside. It will also be seen in Fig. 2, that two rings of plates are required to extend to the full height of the turret. The plates break joint as shown in Fig. 2.

Fig. 2.

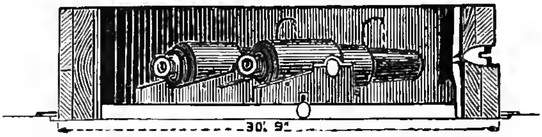


Front elevation of Turret from firing point, &c.

They are all 12 inches thick except the two plates in the upper tier, containing the upper portion of the two gun ports, and in the lower tier the plate between the lower portions of the two ports, which three plates are each 14 inches thick. The wood backing is 17 inches behind the 12-inch plates, and 15 inches behind the 14-inch plates, so as to form an uniform thickness of plate and backing of 29 inches. Inside the backing is a 1½-inch skin, consisting of two ¾-inch plates; then come vertical girders 5 inches deep, and finally on the inside edges of these a mantlet skin of ¼-inch thick, to keep back nuts and bolt heads, &c., from flying about in the turret. It is obvious that the liability of the turret to contortion was most severely tested by firing at the thickest plates, for against the thinner portion there was only the resistance encountered by the projectile in passing through 12 inches, to act in bending; for directly the shot is through the turret, all contorting action is past, whereas, against the thick plates, the shot had to penetrate 14 inches of iron, which thickness, in fact, was more than a match for it.

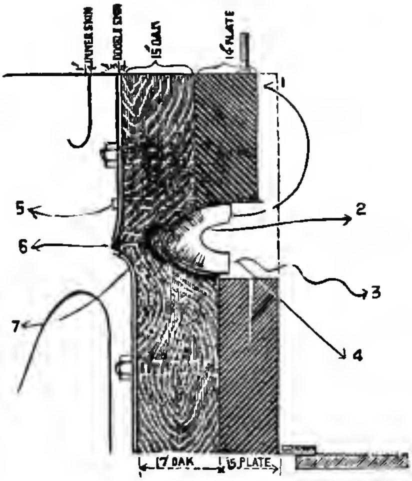
Calculated on the system followed for thin armour in the Director of Artillery's Department, the shot might perforate 14·42 inches of iron, and might therefore nearly get through the armour, but certainly not entirely. The first round was intended to strike the top of the turret, but actually struck a point nearly 3 feet lower down (*vide* Figs. 2, 3 and 4), producing the following effects.[1] The point of the projectile which

Fig. 3.



Vertical section of turret through portion struck.

Fig. 4.



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[1] The striking velocity of the projectile was not taken. Its initial velocity was probably about the tabular one for this gun, viz., 1300 feet, and its striking velocity about 1276. If this be worked out on formula used for thin armour, Chap. II., p. 16, that is,—

$$t = \sqrt[1\cdot6]{\frac{Wv^2}{2g} \times \frac{1}{\pi D} \times \frac{1}{2\cdot53}}.$$

$\log 2g = 5\cdot1590$

$\log \pi = 0\cdot4971$

$\log D\ (11\cdot92) = 1\cdot0763$

$\log \pi D = 1\cdot5734$

$\log k\ (2\cdot53) = 0\cdot4031$

$2 \log v\ (1276) = \begin{cases} 3\cdot1059 \\ 3\cdot1059 \end{cases}$

$\log W\ (600) = 2\cdot7782$

$8\cdot9900$

$\log 2g = 5\cdot1590$

$\frac{Wv^2}{2g} = \underline{6776} \quad 3\cdot8310$

$\log \pi D = 1\cdot5734$

$\frac{Wv^2}{2g} \times \frac{1}{\pi D}\ \underline{180\cdot9} \quad 2\cdot2576$

$\log k = 0\cdot4031$

$1\cdot6 \begin{cases} 4)1\cdot8545 \\ \cdot4)\ 46363 \end{cases}$

$\underline{t = 14\cdot42} \quad 1\cdot1591$

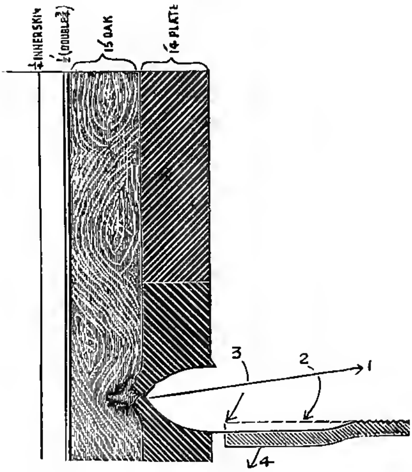
This is an old fashioned gun, and very bad for the rule of thumb, p. 30., Chap. III.

$\frac{1276 \times 12}{1000} = 15\cdot3$ ins.

On Farbairn's formula with table of k, p. 35, Chap. III., the perforation is 13·62.

was fired without any bursting charge (as a shot) penetrated to about 20 inches depth, driving a bolt inwards and dislodging its head. The skin proper was bent and opened to about 3 inches width, a large sheet of mantlet skin was torn off, and a number of rivet heads detached. Above all, the entire upper plate about the place of impact was driven back bodily about 5½ inches, and lifted so as to open the horizontal junction of the plates about 2 inches. A kid, a rabbit, and a hen, which had been put in the turret to try if they would be affected by the shock, did not seem to have suffered in any way. The turret revolved freely. The second round, which consisted of a projectile without bursting charge, as in the previous round, was now directed against junction of turret and glacis plate, and was remarkably successful, it glanced along the glacis plate and entered the base of the turret (*vide* Fig. 5), the point reaching a depth of about 15 inches. The shot was easily disengaged and the turret again was found to revolve and work perfectly. The vessel was nearly as fit for action as before she was struck.

Fig. 5.



It is a question how far the liability to jam might have been more severely tested. The vessel might have had a list given towards the *Hotspur*, as originally intended, to represent the circumstances of plunging fire. Unless the shot, however, had remained with a large part projecting, and had also struck the turret well below the glacis plate, it is hardly likely that the turret would have been jammed. Broken pieces of shot and glacis plate, which latter is only 3½ inches thick, might have got into the 6-inch space round the turret, but the crew would have found access to them from below, without exposing themselves. It was afterwards suggested that the revolving gear would be more severely tried by a blow striking more nearly in a tangential direction, so as to tend to produce sudden rotation, or to check the turret suddenly when in motion. This suggestion however may be probably disregarded safely. The *Glatton* turret is nearly 31 feet in diameter; a projectile with an ogival head of 1½ diameters radius, would probably glance at about 48 degrees with the tangent, or 42 degrees with the normal line to the turret face. This would give a maximum lever of about 10 feet for rotation of the turret. It is very unlikely that such a blow could be made to act on the mass of the turret so as to put it in motion, and certainly the gear which is at the base of the turret could only be affected by the intermediate metal between it and the point of impact being moved in some way.

On the whole, the direct blow at the turret top seems to be the most severe test, and no 12-inch projectile could produce a much greater effect than that first fired on this occasion, for the only additional power to contort the turret, available, is that required to complete the passage of the shot entirely, and this is but little. The introduction of new type guns with small bores has rather favoured the turret in this respect, for a shot of smaller diameter, while it would perforate much more readily, would have less power to contort the structure: and for a new type piece of greater diameter than 12 inches, it is necessary to go above the 43-ton gun, so that the *Glatton* turret may be safely regarded as not liable to be jammed or wedged by any reasonable exposure to fire. It may here be observed, however, that the condition of a turret made of harder armour is not the same. A steel, or even steel-faced plate distributes the shock much more than one of wrought-iron; consequently, where the latter would be perforated, the former may be bodily driven back, and a turret covered with such armour might suffer more in its structure from racking than the former.[1] The total stored-up work, or striking energy is of course the factor to be considered. In the above experiment it was only about 6776 foot-tons, a force, however, which it may be noticed, would be sufficient to lift the turret to a great height in the air, if applied to such a purpose in a suitable form.

Whitworth 9-pr. fired obliquely.

On October 8, 1872, Sir Joseph Whitworth fired a 9-pr. B. L. gun at Southport, Lancashire, against a 3-inch Cammell wrought-iron plate at an angle of 45°. The hexagonal bore of this gun was 2·72 inches measuring from angle to angle, and 2·47 inches from side to side of the hexagon. The length was 8 feet. The pitch of rifling was about 1 turn in 18 calibres, or 50 inches. The projectile was a steel flat-headed shell slightly tapered in front, made from a solid steel ingot bored out. It was 5 diameters (13½ inches) long, and weighed 15 lbs. 14 ozs. One projectile fired at 200 yards range, nearly perforated the plate, and a second one passed completely through it, penetrating some depth into the earth in rear.

Sir J. Whitworth exhibits shells and plates perforated by them at as oblique an angle as 30° with the face of the plate, in support of his contention that flat-headed projectiles bite at a more oblique angle than pointed ones. On this it is difficult to speak authoritatively.

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[1] At Shoeburyness entire targets of steel-faced armour have been driven back bodily many inches, and the structure supporting them has suffered proportionately.

The question has been disputed,[1] both on theoretical and practical grounds. Occasionally pointed projectiles have bitten plates at very oblique angles, but no instance of biting at 30° can be given. With regard to the practical advantage of a possible superiority in the flat-head in this respect, it must be understood that Sir Joseph himself prefers ogival-headed shot for perforation near the direct line, any possible advantage possessed by flat-headed shot would therefore probably only hold for a certain number of degrees, such as could hardly compensate for the admitted advantage possessed by ogival shot in more direct impact. Hence ogival-headed projectiles may be preferred to flat-headed ones for service, even by those who admit that the latter act better through water, and bite at a more oblique angle of incidence against armour.

Tegel experiment 1872.

On August 15, 1872, at the Tegel in Prussia,[2] Krupp's 26^{cm} (10¼-in.) and 28^{cm} (11-in.) guns were fired against 10 and 12-inch iron, backed by 18 inches of oak, and ⅜-inch skin. The 10-inch portion was perforated with the 10¼-inch gun. The 11-inch would penetrate the 12-inch portion at about 437 yards range. These penetrations are not extraordinary, but the German guns were now growing longer, and their power was increasing.

Wet guncotton.

On February 16,[3] and March 30, 1875, some Palliser shells, filled with wet guncotton, were fired against armour, when it was found that shells so charged, with a primer of dry guncotton embedded in the wet guncotton, might be fired safely from ordnance, but that on impact the explosion of the primer was not communicated to the wet guncotton. "The shells appeared to break up on impact outside the plate, probably from the instantaneous explosion of the dry primer, the charge of wet guncotton being thrown about in front of the target."

Guncotton discs.

On or about July 24, 1875,[4] the comparative resistance of malleable iron and steel to the detonation of guncotton was tested. Two 9-oz. discs were fired when suspended 3 inches over the centre of a Low moor ⅜-inch plate—buckling the plate 0·65 inches. A Landore steel plate was more abruptly indented to 1·3 inches.

Shannon Target.

***Shannon* target, "No. 39."**

On July 7, 1875,[5] a structure (known as "No. 39") made to represent the unarmoured portion of the *Shannon* class of vessel, was fired at at Shoeburyness. The target represented a complete section of a ship with guns and dummy detachments on both sides. The iron side on one portion was 1 inch thick, made up of two half-inch plates, and the other portion ¾-inch, consisting of two ⅜-inch plates. The total width of the ship between the sides was 56 feet. After firing with machine guns and ordnance, it was concluded that both sections of the target were proof against the 0·65-inch Gatling, and case shot from the 64-pr. gun. The inch portion was also proof against case shot from 9-inch gun fired with 30 lb. charge, but the ¾-inch portion was sometimes nearly penetrated by these at 200 yards. The greatest effect was obtained with the 9-inch shrapnel. One 9-inch shrapnel killed six dummy men, and wounded one at the gun close to where it entered, it also dismounted the opposite gun on the far side, and blew all the dummies posted at that gun to pieces.

---

[1] *See* Mallet's Papers in "Engineer," January 4, 11, 18 and 25, of 1867; also "Experiments on Competitive Shot," *vide* Chap VI. Sir W. Palliser wished to compete with ogival-pointed shot against Whitworth's flat-headed ones.

[2] "Engineer," April 4, 1873, p. 205. Very's "Development of Armour," p. 444.

[3] D. of A. "Proceedings," Vol. XIV. p. 7.

[4] D. of A. "Proceedings," Vol. XIII., pp. 206, 207.

[5] D. of A. "Proceedings," Vol. XII., p. 162, and Vol. XIII., p. 141.

Both parts of the sides of the section[1] fired at were now made 1-inch thick, one portion consisting of two ½-inch iron plates, and the other of two ½-inch Bessemer steel plates. After practice in February, 1876, direct fire, and at angles of incidence of 45°, 30°, 25° and 20°, the following conclusions were arrived at:—The steel resisted better than the iron in two instances, deflecting the 64-pr. common shell, but in one case it was more torn, and had its rivets sheared more extensively than the iron plates. Common shell plugged, or fuzed with Pettman's G. S. fuze, were apt to break across in few pieces without the explosion of the bursting charge; 13 shells, fuzed with Laboratory percussion fuzes burst well into small pieces. The mantlets caught fire, but had not been rendered non-inflammable.[2] It may be observed the shrapnel break up well under any circumstances, and may therefore be fired plugged.[3]

No. 40 Plate-upon-Plate Target and 38-ton gun.

38-ton gun chambered; "No. 40" target

On October 11, 1876,[4] the 38-ton gun of 12·5-inches calibre was fired at Shoeburyness, at a target identified as "No. 40," which was a typical sandwich[5] section, approved by the Royal Engineers, (*vide* p. 49).

---

[1] D. of A. "Proceedings," Vol. XIV.

[2] By soaking in chloride of calcium.

[3] D. of A. "Proceedings," Vol. XIV., p. 85, gives the results of a few more rounds fired on May 18, 1876.

[4] *Vide* D. of A. "Proceedings," Vol. XIV., p. 214; "Engineer," October 20, 1876; also author's paper, Mechanical Engineers Institution, January, 1879; and Very's "Development of Armour," p. 446.

Here $\log 2g = 5{\cdot}1590$

$$\begin{array}{r} \log \pi = 0{\cdot}4971 \\ \log 12{\cdot}42 = 1{\cdot}0941 \\ \hline \log \pi D = 1{\cdot}5912 \end{array}$$

For $v = 1400$ $\log K = \bar{1}{\cdot}9845$.

$$\begin{array}{r} {\cdot}9)17{\cdot}42 \\ \hline 19{\cdot}36 \end{array}$$

Log W (log 815) $= 2{\cdot}9112$

$$\begin{array}{lr} \text{Log } v^2 \,(2 \log 1421) = & \left\{\begin{array}{r} 3{\cdot}1526 \\ 3{\cdot}1526 \end{array}\right. \\ \cline{2-2} & 9{\cdot}2164 \\ \log 2g = & 5{\cdot}1590 \\ \cline{2-2} \underline{11410} & 4{\cdot}0574 \\ & 1{\cdot}5912 \\ \cline{2-2} \underline{291{\cdot}6} & 2{\cdot}4662 \\ & \bar{1}{\cdot}9845 \\ & 2)2{\cdot}4817 \\ \cline{2-2} \underline{t = 17{\cdot}42} & 1{\cdot}2409 \end{array}$$

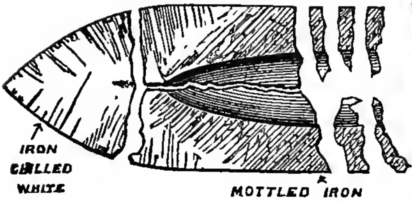
$$\frac{1421 \times 12{\cdot}5}{1000} = 17{\cdot}76 \text{ ins.}$$

Dividing by ·9 for sandwich in 3 plates (*see* Chap. II., p. 18, and Chap. III., p. 35),

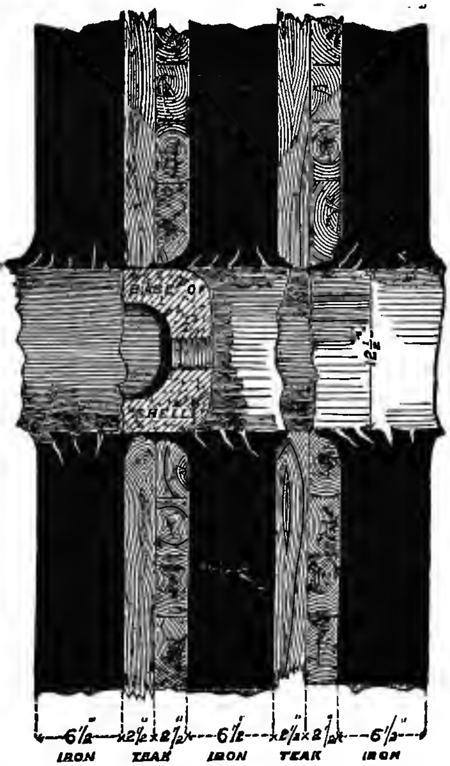
$$\begin{array}{r} {\cdot}9)17{\cdot}76 \\ \hline 19{\cdot}7 \text{ in.} \end{array}$$

[5] Lieut. Very employs the word "plate-upon-plate" for iron plates in contact with each other, and "sandwich" for alternate iron and wood, (*see* Very, p. 446). This might be good if universally followed (*see* note 2, p. 8).

The projectile weighed 815 lbs., the striking velocity was 1421 feet. The shell, fired without bursting charge, perforated the armour as shown in Fig. herewith, breaking up, and leaving its base lodged in the plate. It will be found that calculating the perforation by Fairbairn's old formula, with the table of values for K, p. 35, and with the second power of t, a perforation of solid plate of 17·42 inch is obtained; and taking Inglis' rule of three plates being only $\frac{9}{10}$ the strength of one, the shot should perforate 19·36 inches. This result very closely agrees with that given by the rule of thumb, namely, 19·7 inches, and is nearly correct, for the shell perforated 19·5 inches of iron and 5 inches of wood. This case illustrates what was said in Chap. II., p. 17, as to the plate-upon-plate system coming in at a time when it disguised the errors caused by the use of the old D. of A. form of Fairbairn's formula; for if this example be worked out by this formula, ignoring the difference between solid and plate-upon-plate armour, the error arising from using the old formula and that of ignoring the division of the iron neutralize one another, and give as the perforation 19·5 inches, which happens to be nearly correct.



SECTION THROUGH 800 lb. SHELL AS FRACTURED



SECTION OF Nº 40 TARGET

Air space experiments

On the same day[1] a Palliser projectile was fired from the 38-ton gun as above, striking with a velocity of 1436 feet, a 10-inch wrought-iron plate placed 6 feet 8 inches in front of No. 33 target. The projectile, of course, passed through the front plate, striking the target in rear, not quite directly, and shivering to atoms against it, leaving a characteristic splash or lump of pulverized metal adhering to the face of the target.

On March 27, 1877,[2] at Shoeburyness, the 38-ton gun fired a Palliser shell weighted to 800 lbs., against a 4-inch plate, with a 10-inch plate fixed with an air space of 4 feet 7½ inches between them. The shell passed through the 4-inch plate and broke up, forming a splash of metal against the 10-inch plate, which was very slightly bulged in rear—the splashed metal was very hot.

No. 41 Target and 80-ton Gun.

80-ton gun chambered, and "No. 41 target."

On February 1, 1877,[3] the 80-ton gun was first fired against armour. The gun was then unchambered; its bore was 16 inches in diameter. A Palliser projectile, without bursting charge, weighted to 1700 lbs., was fired with a charge of 370 lbs. of P^2 powder against a structure known as "No. 41" target, consisting of four thicknesses of iron each 8 inches, with 5 inches of teak between the layers. This is shown in Figs. 1, 2, 3 and 4, pp. 51 and 52, from which the dimensions of the plates can be taken. The range was 120 yards, the striking velocity was 1496 feet per second. The projectile penetrated the target to a depth of about 48·8 inches, as shown in Figs. 3 and 4, pp. 52 and 51. The entire target bent at point of impact. It will be seen that its structure was by no means stiff, and the layers of metal were opened and contorted by the blow. The shot itself was fractured into four longitudinally, and also broken transversely. The iron of the plates was good, and the bolts, which were the Palliser English pattern, holding the plates together in pairs, behaved well. The target was driven back 2½ inches on the right, and the wood framing in rear broken and splintered. The point of the shot entered 2·6 inches into the back plate. This round is equal to the perforation of 23·57 inches of iron in a single plate. No factor has been worked out for four plates in sandwich, but for three the perforation is 26·3 inches, and the shot ought to perforate four plates of somewhat greater total thickness than this. The four 8-inch plates, however, make up 32 inches, and the work of perforating 26 inches, when constituting the entire target is much less than that of perforating the front 26 inches of 32 inches of iron, because the last 6 inches are stiffening and supporting the front 26 inches of metal. Hence, in default of a formula for partial penetration, there is no cause of surprise at the fact that the point of the shot[1] only penetrated through 26·6 inches.

---

[1] *Vide* D. of A. "Proceedings," Vol. XIV., p. 214, and "Engineer," October 20, 1876.

[2] D. of A. "Proceedings," Vol. XV. p. 107.

[3] D. of A. "Proceedings," Vol. XV., p. 38; "Engineer," February 9, 1877, Author's report.

Here $W = 1700$. $v = 1496$. $D = 15{\cdot}92$.

$\underline{\log 2g = 5{\cdot}1590}$

$\log \pi = 0{\cdot}4971$

$\log 15{\cdot}92 = 1{\cdot}2020$

$\underline{\log \pi D = 1{\cdot}6991}$

For $v = 1500$

$\underline{\log k = \bar{1}{\cdot}9777}$

For 3 Plates—

$\cdot 9)\ 23{\cdot}57$

$26{\cdot}2$

$\log 1700 = 3{\cdot}2305$

$2 \log 1496 = \begin{cases} 3{\cdot}1749 \\ 3{\cdot}1749 \end{cases}$

$9{\cdot}5803$

$5{\cdot}1590$

$4{\cdot}4213$

$1{\cdot}6991$

$2{\cdot}7222$

$\bar{1}{\cdot}9777$

$2)\ 2{\cdot}7445$

$1{\cdot}3723$

$\underline{E = 26382}$

$\underline{e = 528}$

$\underline{t = 23{\cdot}57}$

FIG. 1

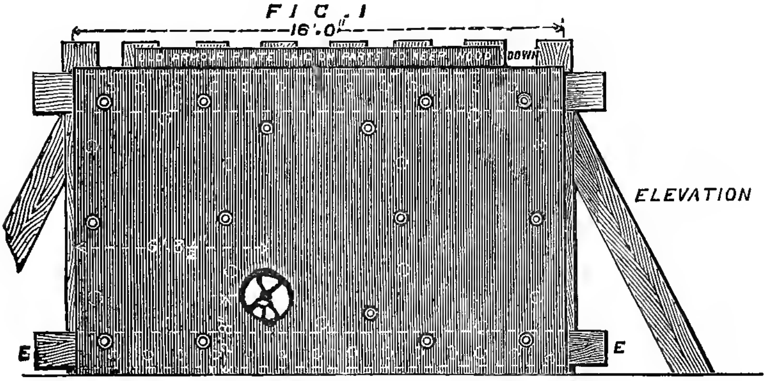
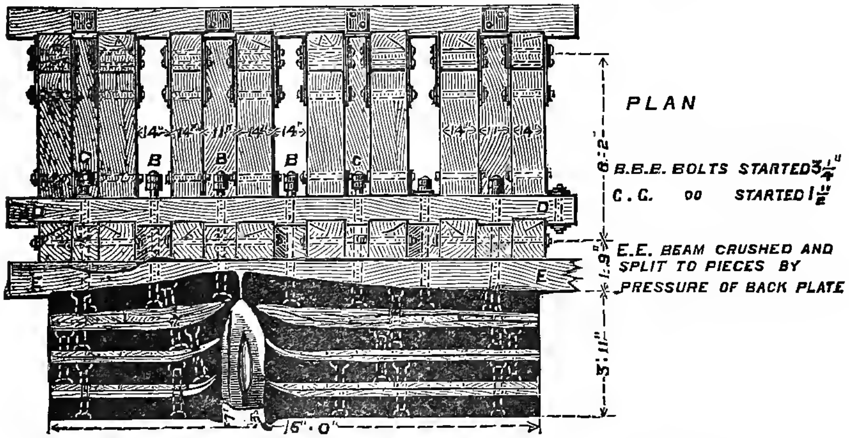


FIG. 4


PLAN
14" 14" 11" 14" 14"
14" 11" 14"
C
B
B
B
C
D
D
E
E
6'·2"
B.B.B. BOLTS STARTED $3\frac{1}{4}$"
C.C. DO STARTED $1\frac{1}{2}$"
E.E. BEAM CRUSHED AND SPLIT TO PIECES BY PRESSURE OF BACK PLATE
1'·9"
3'·11"
16'·0"

Common shells fired at armour.

On the same day, a blind common shell was fired from the 80-ton gun at an unbacked 8-inch plate. The shell passed through the plate, apparently breaking up as it did so, the hole being about 20 inches in diameter, and the plate broken into 5 pieces. The shell fragments, which were small, ranged up to 1200 yards.

---

[1] The point here refers, of course, to the actual tip of the shot. Perforation does not mean that the point shows through, but refers to the actual passage of the entire shot. Exact perforation would be when the shot just got through and was unbroken. Though this cannot exactly occur, something nearly equivalent to it may do so.—*Vide* p. 49.

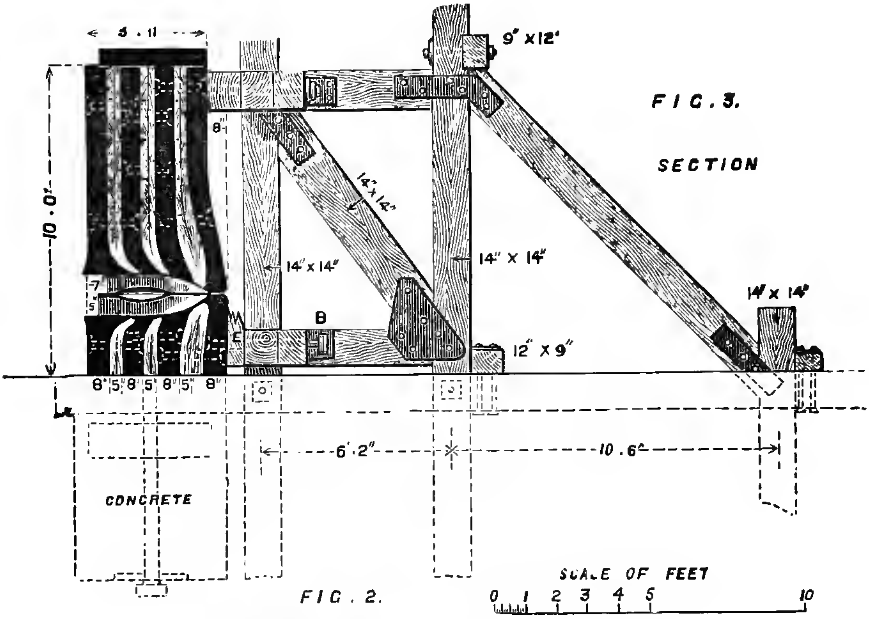
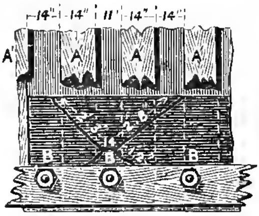


FIG. 3.

SECTION

FIG. 2.



VIEW OF CRACKED AND BULGED BACK PLATE OF TARGET OPPOSITE POINT OF IMPACT. BEAM ENDS OF A'. A'. ARE SHEWN AS IF CUT AWAY TO ENABLE CRACKED TARGET PLATE TO BE SEEN.
BOLTS B. B. B. ARE STARTED ABOUT 3¼ INS OWING TO BEAMS IN FRONT OF D BEING CRUSHED UP AND SPLIT.

Common shell. On March 16, 1877,[1] two 10-inch common shell were fired against 5-inch iron plates at Shoeburyness, one shell filled and plugged, and the other filled and fuzed, in both cases the shell passed through the plates exploding its bursting charge. In the first case, the shell may have acted rather less quickly than the fuzed shell, as the front of the plate was not blackened by the powder. Fig. 5, p. 53, shows the plate struck by the fuzed shell. The torn piece is bent towards the firing point, which seems to imply that the explosion acted chiefly after the shell passed through.

Fig. 4, p. 54, shows a portion of the plate driven out by the plugged shell. It is said[2] that discs of this kind are apt to be formed by common shell, and that the concentric ring gashes, and rends are due to the fact that the apex of the shell yields and is first driven in, followed by successive rings of metal in the crown or head, until the support of the walls is sufficient to enable the projectile to separate the disc from the rest of the plate. The impression made by the square key hole of the gun-metal shell plug was remarkably distinct.[1]

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[1] D. of A. "Proceedings," Vol. XV. p. 76. "Engineer," March 28, 1877.

[2] By Mr. Forest, of the Royal Laboratory.

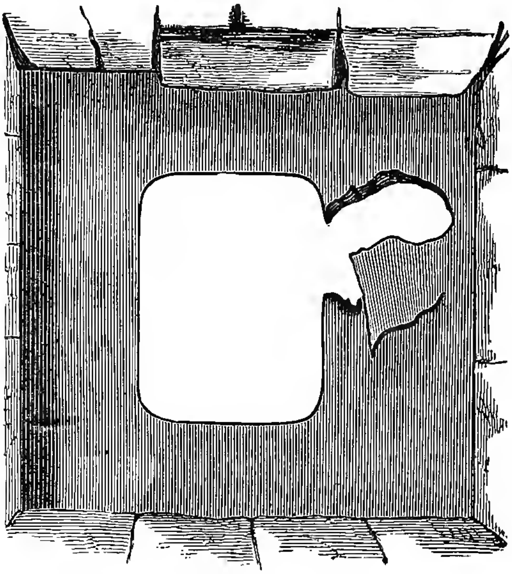


FIG. 5

5 INCH CASEMATE PLATE AFTER BEING BROKEN BY 10 INCH COMMON SHELL MASONRY LOOSENED ABOVE CASE MATE.

Fig. 6, p. 54, shows the projectile fired from 80-ton gun as above described when small fragments had been removed. It may be seen to be fractured longitudinally in horizontal and vertical planes. A considerable mass of metal was left in a diamond form, the angles being at the longitudinal cracks. If this be compared with other fractures it appears to be in conformity with some law, though it is difficult to say what.

Judging by these three experiments with common shell it may be concluded that a common shell will perforate iron plates of the thickness of half their calibre. Backing would impede their further course very greatly, seeing that they are broken, besides the fact that they drive out a disc of plate in front of them.

---

[1] This is an illustration of a softer metal pressing in a harder one. The same thing occurs sometimes when gun-metal studs cut into a steel tube of a gun. Probably the gun-metal yields up to a certain point, after which it offers more resistance than the metal opposed to it.

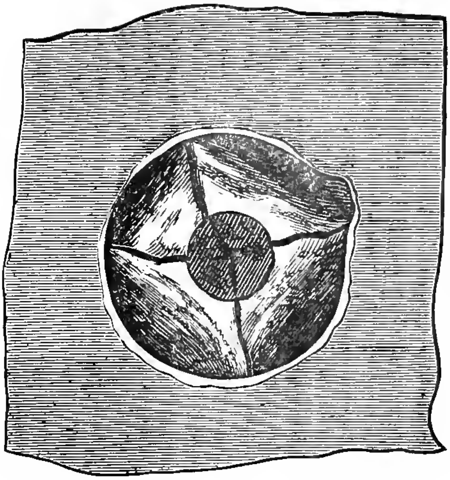


FIG. 6

SHOT OF 80 TON GUN BROKEN IN TARGET

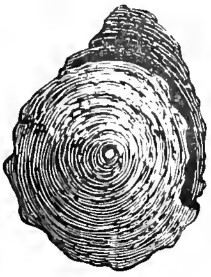
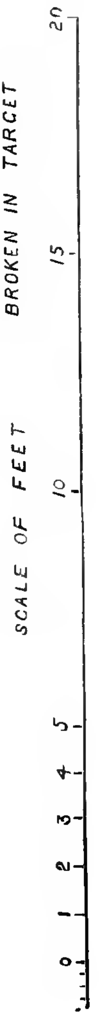


FIG. 4

CENTRAL FRAGMENT OF 5" PLATE BROKEN BY APEX OF COMMON SHELL



No. 40 Target and 38-ton gun, chambered.

38-ton gun, chambered; No. 40 target strengthened

On the same day, March 16, 1877,[1] the 38-ton gun, which had now an enlarged powder chamber, with a diameter of 14 inches, the bore being 12·5 inches, was fired against No. 40 target at Shoeburyness. The firing charge was now increased from 130 to 200 lbs. of pebble powder, P², 1·5-inch cube. The gun was 70 yards from the target, the striking velocity was 1525 feet, the muzzle velocity having been 1540 feet. A Palliser projectile without bursting charge was employed, weighing about 812 lbs. It was fired against the strengthened part of the target, consisting of four 6½-inch plates, with 5-inch layers of wood, sandwich, between them (*vide* Figs. 1, 2 and 3, herewith, and p. 56). The projectile penetrated deep enough to get its point probably about 2 inches into the last plate. The back of the target showed a slight horizontal crack opposite the point of impact. The shot itself was split longitudinally into four at the base, and was also broken transversely. The whole target was bent, but the bolts and iron plates behaved well. The total energy, energy per inch circumference, and thickness of plate that represents the full perforating power are respectively 13090 and 335·5 foot-tons, and 18·79 inches solid plate, or 20·9 in three layers, (*vide* note, p. 56). The point in this instance probably had penetrated about 18·5 inches, which is about what might have been expected,

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[1] "Engineer," March 23, 1877, also author's paper on "Construction of Armour," Institution of Mechanical Engineers, 1879. D. of A. "Proceedings," Vol. XVI., p. 103.

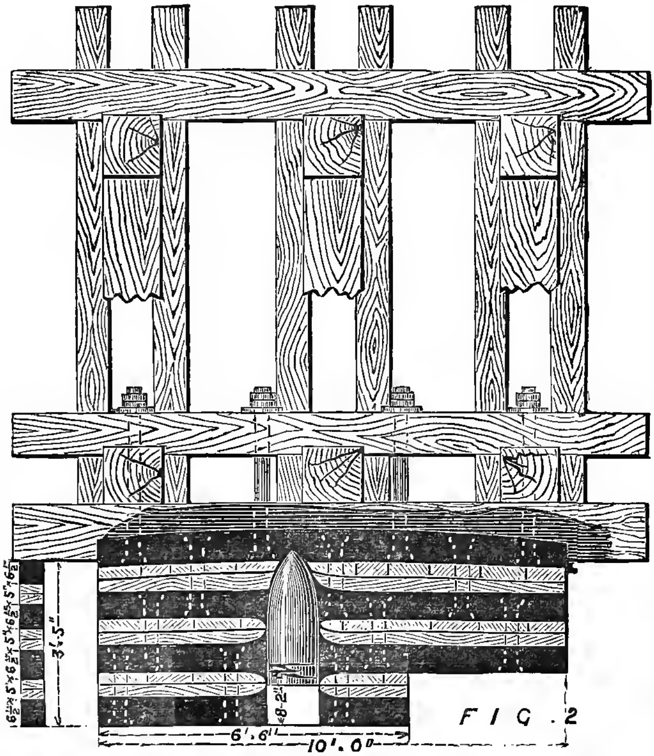

FIG. 2

PLAN

considering that it is a case of partial penetration into iron of a total thickness of 26 inches.[1]

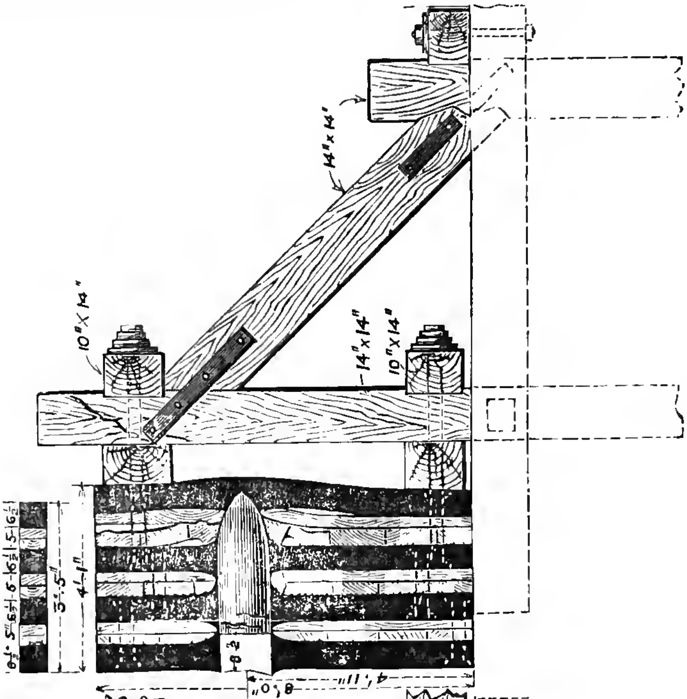

FIG. 3 VERTICAL SECTION

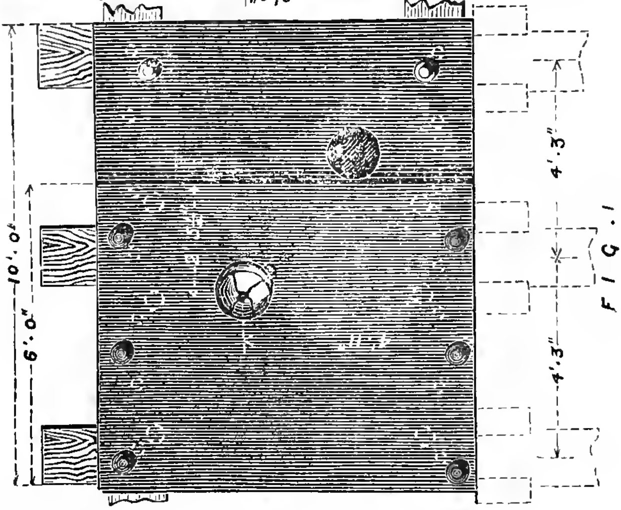

FIG. 1 ELEVATION

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[1] $W = 812$. $v = 1525$.

$\text{Log}\ \pi = 0{\cdot}4971$

$\text{Log}\ 12{\cdot}42 = \underline{1{\cdot}0941}$

$1{\cdot}5912$

For $v = 1500$ $\underline{\log K = \bar{1}{\cdot}9777}$.

$\text{Log}\ 812 = 2{\cdot}9096$

$2 \log 1525 = \begin{cases} 3{\cdot}1832 \\ 3{\cdot}1832 \end{cases}$

$9{\cdot}2760$

$5{\cdot}1590$

$E = \underline{13090 \text{ ft. tons}}$ … $4{\cdot}1170$

$1{\cdot}5912$

$e = \underline{335{\cdot}5} \text{ ft. tons}$ … $2{\cdot}5258$

$\bar{1}{\cdot}9777$

$t = \underline{18{\cdot}79} \text{ ins.}$ $2)\ 2{\cdot}5481$

$1{\cdot}2741.$

$\cdot 9)\ \underline{18{\cdot}79}$

$20{\cdot}8$

Another shell was fired against the thinner portion of the plate on July 20, 1877, to which was added a 3-inch plate in front, making 22½ inches of iron and 10 of wood. The projectile was 811 lbs. 4 oz. It penetrated till the point was 28½ inches, measured from the front of the target proper. This would amount to about the same penetration through iron as in the case of the last round. The shot was much broken up, and there were marks on the second plate resembling the "splashes" in air space targets.[1]

No. 41 Target and 80-ton gun, chambered.

80-ton gun, chambered, and No. 41 target.

On May 4, 1877,[2] the 80-ton gun was fired a second time at No. 41 target. The gun had now been chambered to a diameter of 18 inches, the bore being 16 inches as before. The firing charge was 425 lbs. of P_2 powder, 1·5-inch cube. A Palliser projectile, without bursting charge, weighing 1700 lbs., was fired with a muzzle velocity of 1600 feet, and a striking velocity at the plate 120 yards distant from the gun of 1585 feet. The striking energy, *E*, was therefore 29,610 foot-tons. The thickness of solid iron that might be perforated was by Colonel Maitland's diagram 24·5 inches, and by Colonel Inglis 24·7 inches. By the rule of thumb 25·4 inches. By Fairbairn's formula it is 25·1 inches, and if disposed in three thicknesses 27·9 inches. The point of the shot actually penetrated a distance of about 56 inches from the face of the target, but owing to the giving back of the whole structure (*vide* Figs. 2 and 3, pp. 58 and 59), this amounted to a penetration of about 3 inches into the last plate. That is about 27 inches of iron in all. The hole in the front plate was slightly larger than the diameter of the shot. The back plate was bulged nearly 14 inches and cracked in five lines, radiating from the spot opposite to the point of impact, and opened sufficiently wide to show the point of the shot. The timbers were split and crushed, as shown in the Figs. 2 and 3, pp. 58 and 59. Fig. 1, p. 58, shows the front of the target, and Fig. 4 the back opened by shot.

This concludes the series of rounds with the 80 and 38-ton guns against their respective sandwich targets, No. 41 and 40. The following round was, however, fired against a solid plate for the sake of comparison with No. 40 sandwich target, which ought to be connected with them.

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[1] D. of A. "Proceedings," Vol, XVI., p. 104.

[2] D. of A. "Proceedings, Vol. XV., p. 99 ; "Engineer," May 11th, 1877.

Log πD = 1·6991

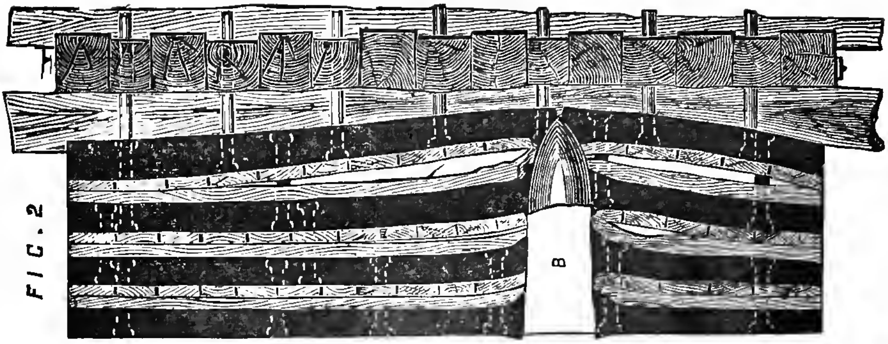
For v = 1600

log K = $\bar{1}$·9731

For 3 Plates—

$$\begin{array}{r} \cdot 9)\ 25{\cdot}10 \\ \hline 27{\cdot}9 \end{array}$$

$$\begin{array}{lr}
\text{Log } 1700 = & 3{\cdot}2305 \\
2 \log 1585 = & \left\{\begin{array}{r} 3{\cdot}2000 \\ 3{\cdot}2000 \end{array}\right. \\
\hline
 & 9{\cdot}6305 \\
 & 5{\cdot}1590 \\
\hline
E = \underline{29610} \text{ ft. tons} \quad \ldots \quad \ldots & 4{\cdot}4715 \\
 & 1{\cdot}6991 \\
\hline
e = \underline{592{\cdot}1} \text{ ft. tons} \quad \ldots \quad \ldots & 2{\cdot}7724 \\
 & \bar{1}{\cdot}9731 \\
 & 2)\ 2{\cdot}7993 \\
\hline
t = \underline{25{\cdot}10} \text{ ins.} \quad \ldots \quad \ldots & 1{\cdot}3997
\end{array}$$



HORIZONTAL SECTION

FIG. 2

VIEW OF BACK OF TARGET WITH SHOT POINT VISIBLE IN OPENING

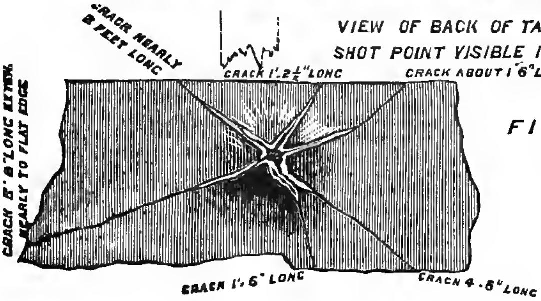


FIG. 4

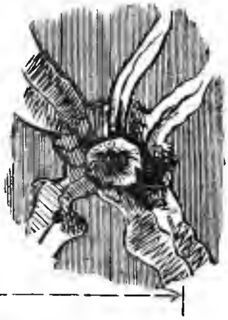
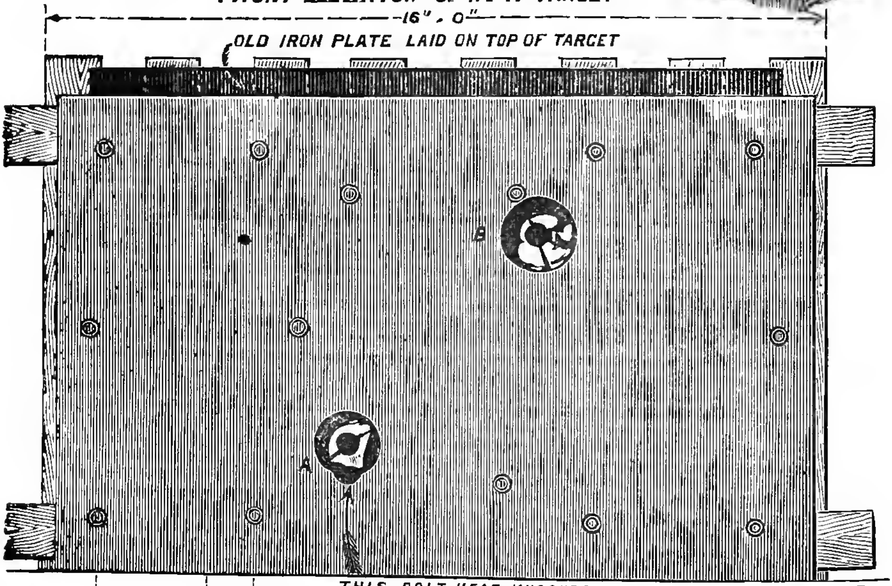


FIG. 1

FRONT ELEVATION OF No. 41 TARGET



THIS BOLT HEAD KNOCKED OUT & SEEN AS A DARK HOLE

A PROJECTILE FIRED FROM UNCHAMBERED GUN

B Do. Do. FROM CHAMBERED GUN

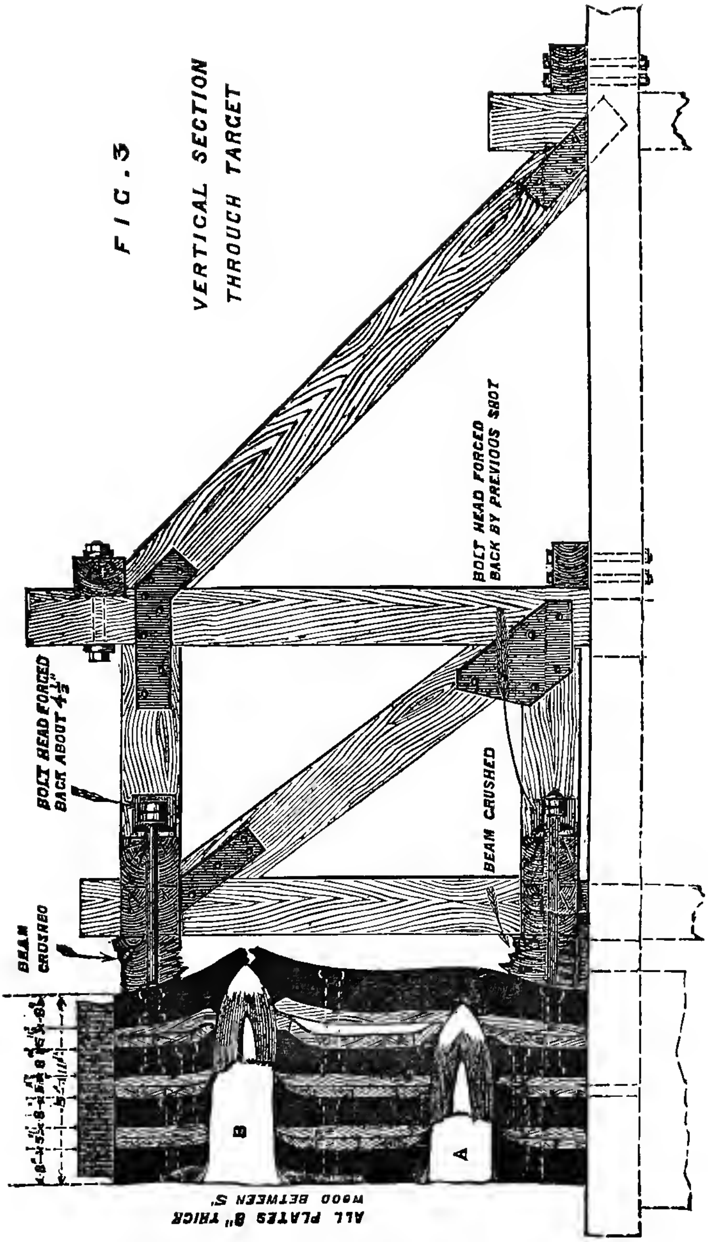


FIG. 3

VERTICAL SECTION THROUGH TARGET

BOLT HEAD FORCED BACK ABOUT 4½"
BEAM CRUSHED
BEAM CRUSHED
BOLT HEAD FORCED BACK BY PREVIOUS SHOT
A
B
ALL PLATES 8" THICK WOOD BETWEEN S'

Solid plate tested by 38-ton gun.

16½-inch solid plate target.

On August 1, 1877,[1] at Shoeburyness, the 38-ton 12·5-inch gun was fired at solid 16½-inch wrought-iron plate. This plate had been ordered for comparison with the round fired from the gun when unchambered at the three plates forming No. 40 target, before it was strengthened (*see* p. 49). In his paper on "Targets for the trial of Heavy Ordnance," General Inglis says, "Having obtained in round 2039, so exact a measure of the penetrative power of the 38-ton gun upon a three-plate target, it was thought that we could not do better than use this result as our datum, and endeavour to obtain an equivalent result with the same gun upon a single plate. Accordingly, after due consideration of former trials, it was settled that the single plate for comparison should be 16½ inches thick, and an armour plate of this thickness, measuring 8 feet × 8 feet was ordered." "The finished plate, as set up at Shoeburyness weighed 18¾ tons." For trial, the plate rested against supports at its top and bottom edges to prevent being driven back, and it was held from falling forwards by two bolts through its upper corners." The plate was good and sound.

The projectile was a Palliser shell, 12·43 inches diameter over body, weighted with sand to 817 lbs., including gas check. It was fired with 175 lbs. of P_2 powder, giving it a striking velocity of 1410 feet per second, and a striking energy, E, of 11,263 foot-tons, and a power to penetrate thickness of iron, t, of 17·29 inches.[2] The shell struck a point 2 feet 10 inches from left edge, and 2 feet 11 inches from top, and passed entirely through the plate, making a round hole 13 inches in diameter, with a lip of 2 to 3 inches round the front edge. A crack was formed from the left edge of the plate nearly up to the shot hole, extending through the thickness of the plate at the edge. The plate buckled from ¼ to $\frac{1}{16}$ of an inch, and moved forward bodily about 5½ inches. The projectile was broken up small, but its fragments all passed entirely through the plate, including its gas check. The metal was of average quality.

Comparing this result with the first round at No. 40 target, General Inglis observes "It will be seen that the shell had rather more force to spare with 11,263 foot-tons energy, in perforating the single 16½-inch plate, than with 11,410 foot-tons in perforating the 19½ inches in three sandwich plates. He therefore considers that a 17 or 17½-inch solid plate would have been the equivalent of the three 6½-inch plates disposed sandwich fashion, as in No. 40 target. It will be seen that according to General Inglis' factor for plate-upon-plate targets (Chap. II., p. 18), that armour divided into three plates has $\frac{9}{10}$ the resisting power of the same thickness solid. Thus, 19½ inches would be equivalent to about 17·5 inches solid, as indicated above by actual experiment.

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[1] D. of A. "Proceedings," Vol. XVI., p. 103; No. of round, 2069.

[2] Worked out on p. 441, Vol. XIII.

As to the entire series of experiments against No. 40 and 41 sandwich targets, the most striking features are the toughness and flexibility of these structures, which would probably bear continued fire well, they would therefore be adapted to resist the fire of any projectiles which were unable to perforate them completely, and for forts where additional plates could be added in front, as time goes on, to meet the growing power of ordnance, this structure seems very good. The Palliser English bolts stood admirably. Of course, for ships, where the contortion would be serious, the case is different.

Air space.

One other round was fired from the 38-ton gun, on August 1, 1877,[1] at a 4-inch plate, set up 18 inches in front of an old 10-inch plate. The projectile, a Palliser shell, made a hole 13 inches in diameter in the front plate, and the point entered 5½ inches into the 10-inch plate, which was broken into several pieces, the base of the shell splashed the face of the 10-inch plate. The effect in this case was apparently considerably greater than in the round fired on March 27, previous (*see* p. 50), the air space being reduced from 4 feet 7½ inches to 18 inches.

Krupp Sandwich.

About this time a Krupp 12-inch gun,[2] was fired at a sandwich target, consisting of 10 inches of iron, 8 inches of oak, 6 inches of iron, 8 inches of backing, "strengthened by iron stringers and a skin of two 1-inch plates." The range was 225 yards, charge 132 lbs., projectile 670 lbs. Both plates were pierced, the point of the shot entered the backing 7½ inches, bending the skin-plating back 3 inches.

It may appear by General Inglis' rule that the plates would represent about 15½[3] solid, but this is not the case, for the conditions are altered by the thickness of the intermediate layers of wood (*see* Figs., Meppen Trials, 1879 and 1882, Chaps. V. and VI.).

The projectile would get its point clear of the front plate and enter the second one, attacking the plates in succession, without their receiving the strength from each other that they would get with 5 inches of wood only.

The notable Spezia trials of steel and iron plates by the 100-ton gun occurred at the end of 1876, previous to the firing of the 80-ton gun, but it appears undesirable to break up the series of sandwich target experiments. Moreover, the introduction of steel and other hard armour so entirely changed the character of plate experiments, that it seems better to commence the series of hard armour trials in a separate section. Since, however, soft and hard armour were occasionally compared together, it is difficult or impossible to keep the two classes of experiments apart, that is, those dealing with penetration and those dealing with shattering. In the ensuing chapter, then, will be found experiments with competitive shot whose merits were judged up to a certain point wholly by perforation, also some experiments of Krupp's, at Meppen, both in 1879 and 1882, on perforation (*see* Chaps. V. and VI.). Also at Shoeburyness and Spezia wrought-iron plates were used in comparison with those faced with steel or wholly made of steel.

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[1] D. of A., "Proceedings," Vol. XVI., p. 103.

[2] Very's "Development of Armour," p. 447.

[3] That is, $16 \times \frac{96}{100} = 15{\cdot}36$.

Chilled-iron armour, which constitutes a very distinct class, is kept chiefly in a section of its own, but here and there comes into the programme of experiments on wrought-iron and steel shields when compared with them.

CHAPTER V.

SPEZIA TRIALS, 1876, WITH 100-TON ARMSTRONG M.L. GUN, AND FIRST TRIALS OF STEEL-FACED IRON PLATES.

The employment of steel armour at Spezia, in 1876, was attended with such remarkable results, that to these must mainly be traced the stimulus given to the trial of steel in armour in this country. The character of the Spezia experiments is peculiar. The object was to test the power of the 100-ton M.L. gun of 17-in. calibre, made by Sir W. Armstrong & Co., and delivered in Italy in 1875, and further to determine the kind of armour that could best be applied to the turrets of the vessels *Duilio* and *Dandolo*, then in course of construction: the thickness of 21·65[1] inches of plate, 29 inches of backing, strengthened by angle-iron, and 1½ inch of skin, having been previously decided on. The experiments were commenced on 20th October, 1876, but the armour was actually fired at first on 25th October. The several descriptions of targets tried are shown in the accompanying series of sections.

The same tests were applied in succession to the various targets, with certain exceptions, and with effects shown generally in[2] the figures in successive rows. The top figures exhibit the effect produced by one 10-inch projectile on every section; with the exception of the three forming the lower halves of Figs. 2, 3, and 4 A, which are shown uninjured. Figs. 1, 2, 3 and 4 B represent the same sections after being further subjected to the blow of one 10-inch and one 11-inch projectile fired in a salvo; the same three sections (forming the lower halves of Figs. 2, 3, and 4 B) again escaping any trial. Figs. 1, 2, 3, and 4 C, show the effect of one projectile from the 100-ton gun on every target.

The tests thus systematically applied consist, first of one round from a gun of comparatively small power; secondly of a salvo from two guns of small power, the 10-inch and 11-inch guns being only capable of piercing plates of about 13¾ and 14¾ inches thickness at the most; and lastly of one round from a gun which was much more than a match for the target, the 100-ton gun being capable of penetrating between 30 and 31 inches of armour.[1] The two salient features of the experiment are, first the powers of the various sections to withstand the effect of comparative light artillery; and secondly the effect produced on the same sections by the shock of artillery fire which is much more than a match for them. No. 1 in each series exhibits Cammell's solid 22-inch wrought-iron plates in the upper half, and Marrel's in the lower. No. 2 shows Schneider's solid 21·65-inch steel plates in both upper and lower tiers. Nos. 3 and 4 show sandwich targets. Of these the upper portions had front plates of iron 11·81 inches (30^{cm}) thick, then 10 inches of wood, next 9·84 inches (25^{cm}) of iron, and lastly 19 inches of wood, with skin; the iron in No. 3 section was supplied by Marrel, and in No. 4 by Cammell. The lower portions of Nos. 3 and 4 consisted of 14 inches of chilled cast-iron behind 8-inch front plates of wrought-iron, 10 inches of wood being sandwiched between the chilled and the soft iron in No. 3, while these were in contact in No. 4, as shown in Figs.

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[1] 55 centimetres.

[2] These drawings were not made on the ground by the author, who did not witness this experiment. They are taken from the official sections of the Italian Government, on which were entered the effects noted, which were afterwards submitted to an officer, who was present, to check and correct them. It is, of course, impossible to show effects at all completely in a single section. These are only intended to enable the mind to grasp and compare general effects readily.—*Vide* "Engineer," December 29th, 1876, and January 5th, 1877.

The effects admit of being dealt with generally. The 10-inch projectile in the first test (Figs. 1, 2, 3, and 4 A) penetrated about 10 inches: the depth being greatest in the softest iron, Cammell's (Fig. 1 A, upper portion); less in Marrel's iron (Fig. 1 A, lower portion), but accompanied with more cracking; and still less in the steel (Fig. 2 A), with considerable cracking.

When the salvo was fired, the same results relatively were produced in a much more marked degree (Figs. 1, 2, 3, and 4 B). Considerable penetration (about 13 inches) was obtained in Cammell's solid plate (Fig. 1 B, upper portion), a large piece of plate was detached from Marrell's (Fig. 1 B, lower portion), and Schneider's steel plate was so much split (Fig. 2 B) that it was clearly far advanced towards destruction. It thus became evident that steel was quite unsuited to withstand the continuous fire of even comparatively light guns.

The projectile from the 100-ton gun, on the other hand, passed with ease through the iron structures[2] (Figs. 1 C); while the two steel

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[1] The calibre of the gun then fired was 17 inches. The projectile weighed about 2000 lbs. It was fired with charges of about 341 lbs., giving striking velocities of from 1475 to 1500 feet. The targets faced the sea a short distance from the gun, which was mounted on a raft.

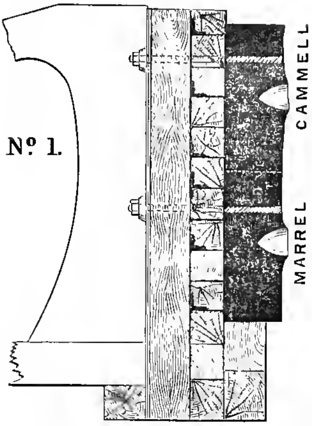
[2] It broke up, however, interfering with an interesting experiment which was made to measure the work absorbed in perforation, by taking the velocity of the shot after passing through the entire target. The striking velocity of this round was 1478 feet, the weight of shot was 2000 lbs., the energy was therefore 30,296 foot-tons. After passing through the target the velocity was 600 feet. This, if true of the entire shot, gives 4,993 foot-tons energy remaining in the projectile; that is, 25,303 foot-tons had been absorbed in penetrating the target.

$$\begin{array}{lr} \text{And} \quad \text{Log } 25303 = & 4{\cdot}4032 \\ \text{Log } (\pi \times 16{\cdot}92) = & \underline{1{\cdot}7255} \\ & 2{\cdot}6777 \\ \log K = & \underline{\bar{1}{\cdot}9912} \\ 2) & \underline{2{\cdot}6865} \\ \underline{t = 22{\cdot}07 \text{ ins.}} & 1{\cdot}3438. \end{array}$$

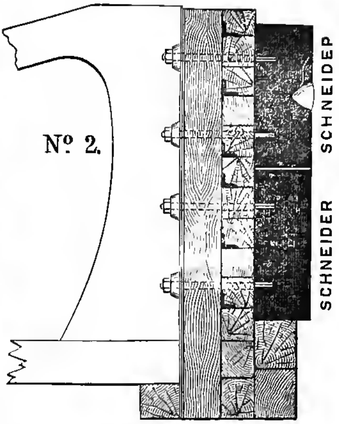
Log K is taken, supposing v to be about 1300 feet; v might be worked out easily by subtracting logs of g and W from 4·4032; halving and looking out the corresponding log.

The highest striking velocity against plates was 1500. The weight of shot being 2000 lbs., and the diameter 16·92 inches, the total energy E=31,200 foot tons, the energy per inch circumference e=587 foot-tons, and perforation t=24·86 inches. One round fired against earth had a velocity of 1543 feet, and an energy E=33,020 foot-tons.

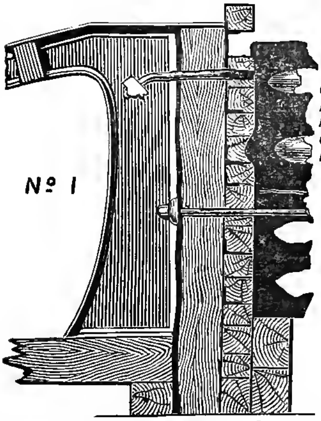
1 A.



2 A.



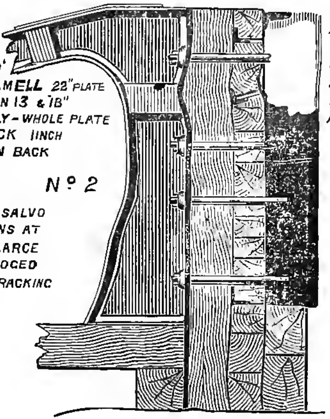
1 B.



5TH FIRE. SALVO 11" & 10" GUNS. AT CAMELL 22" PLATE PENETRATION 13 & 18" RESPECTIVELY—WHOLE PLATE DRIVEN BACK 1 INCH BOLT DRIVEN BACK

6TH FIRE. SALVO 11" & 10" GUNS AT MARREL. LARGE MASS DISLODGED AND MUCH CRACKING

2 B.

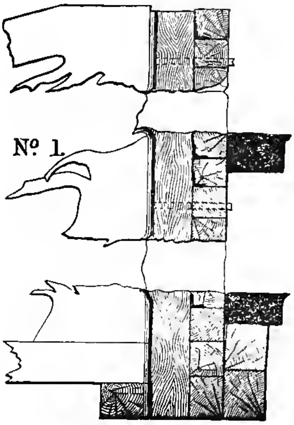


4TH FIRE. SALVO 11" & 10" GUNS. AT SCHNEIDER STEEL 22" PLATE. LARGE PIECE DISLODGED AND GREAT CRACKING

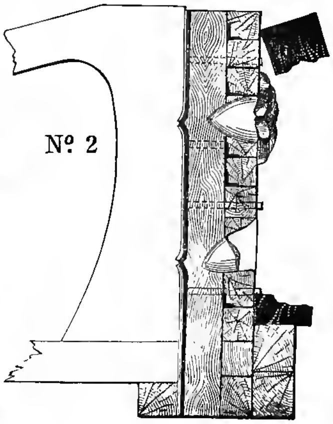
CAMMELL & MARREL
IRON PLATES
EACH TARGET AFTER BEING STRUCK BY
1 ROUND 10" SHOT
SALVO—10" AND 11" SHOT

SCHNEIDER
STEEL PLATES
UPPER TARGET AFTER BEING STRUCK
1 - 10" SHOT
SALVO - 10" AND 11" SHOT

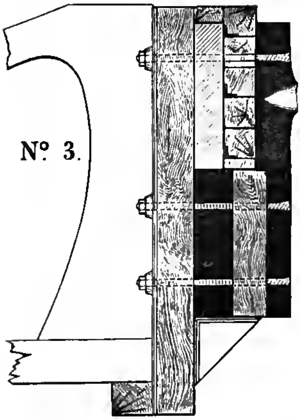
1 C.



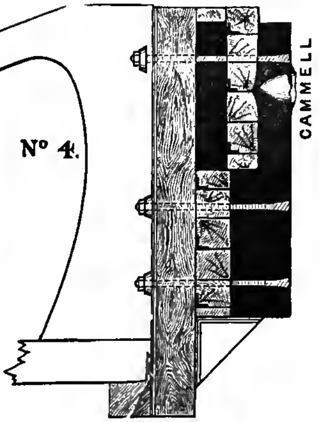
2 C.



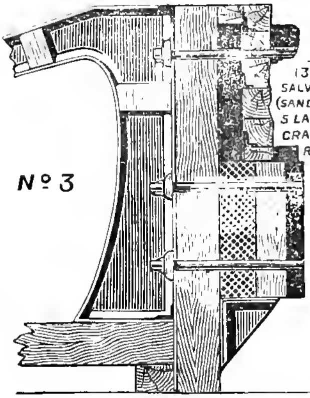
3 A.



4 A.



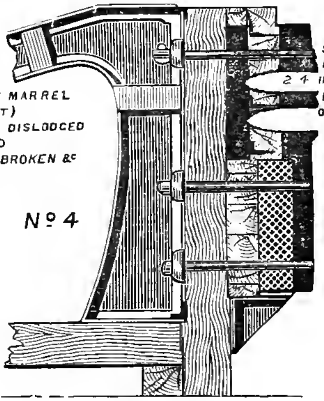
3 B.



13th ROUND
SALVO 11" & 10" AT MARREL
(SANDWICH TARGET)
5 LARGE PIECES DISLODGED
CRACKS FORMED
RIVETHEADS BROKEN &c

MARREL
IRON (SANDWICH) PLATES

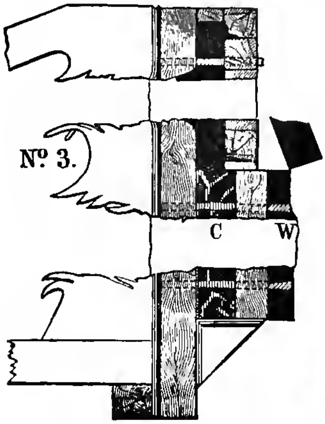
4 B.



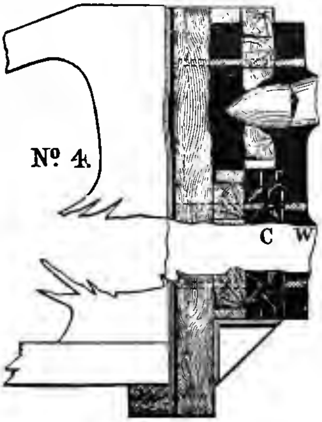
14th FIRE
SALVO 11" & 10"
GUNS. PENETRATION
2 4 INTO REAR PLATE
RIGHT TOP CORNER
OF PLATE DISLODGED

CAMMELL
IRON (SANDWICH) PLATES

3 C.



4 C.



plates (Fig. 2 C) in the act of shivering under its blow so far absorbed the work stored up, that the projectiles did not penetrate the backing, the points remaining as shown in Fig. 2 C. Doubtless attention will be attracted by the projectile of the 100-ton gun being also shown as failing to penetrate No. 4 upper target (Fig. 4 C); in that instance however the shot was fired with a charge so greatly reduced, that its penetration ought only to be equivalent to about 19 inches of plate, and the result accords fairly well with what would be calculated.

The features to notice here are, that *steel is well calculated to enable a vessel to bear a single blow of the projectile from a gun which is much more than a match for the same thickness in wrought-iron; while on the other hand such plating must be expected to crumble under the continuous fire of guns which could not easily injure wrought-iron of the same thickness.* The *Duilio,* if clad in steel 22 inches thick, might probably run past a fort mounting any guns existing; but she might be gradually destroyed by the continuous fire of almost any of our more recently constructed ironclads.

In every instance the plates were broken across by the projectile of the 100-ton gun; consequently great fault has been found with the Spezia experiments on account of the narrowness of the plates. If the object was to test plates of the size which was to be used on the ships, this objection scarcely holds, the design of the ship, showing a belt of thick armour of the same width as the plates actually fired at, namely 4 feet 8 inches. On the principle which was laid down in considering wrought-iron, the 10-inch wood layer in the sandwich targets appears much too thick. The chilled iron was used in a manner wholly unsuited to bring out its powers, and failed, as might be expected, *vide* Figs. 3 and 4 C. The plates were easily broken up, and the results do not deserve careful consideration.

The result of the Spezia experiments called the attention of the authorities in England to the peculiar powers of steel to such purpose, that it may be said from this date, the investigation was carried on under the conviction that steel in some form must replace iron sooner or later, although the breaking up *en masse* of steel was regarded as an evil which must, if possible, be prevented. Messrs. Cammell had proposed compound armour plates, consisting of a steel face united by fusion to a wrought-iron foundation plate, on a patent of Mr. George Wilson's,[1] which offered the advantages of a hard surface, and a tough mass or body. This seemed to promise well, and trials with it followed quickly.

Wilson's compound (steel-faced) armour trial.

Wilson's compound armour.

On August 1, 1877, (the day of the trial of the 16½-inch wrought-iron plate noticed before, p. 138) at Shoeburyness, a small "compound" plate about 8 ft. 7 in. by 3 ft. 6 in. and 9 ins. thick, was fired at by a 7-inch gun, with Palliser shot weighing 115 lbs., with a 30 lb. charge, at 70 ft. range, the striking velocity being 1456 ft.[2] The plate was

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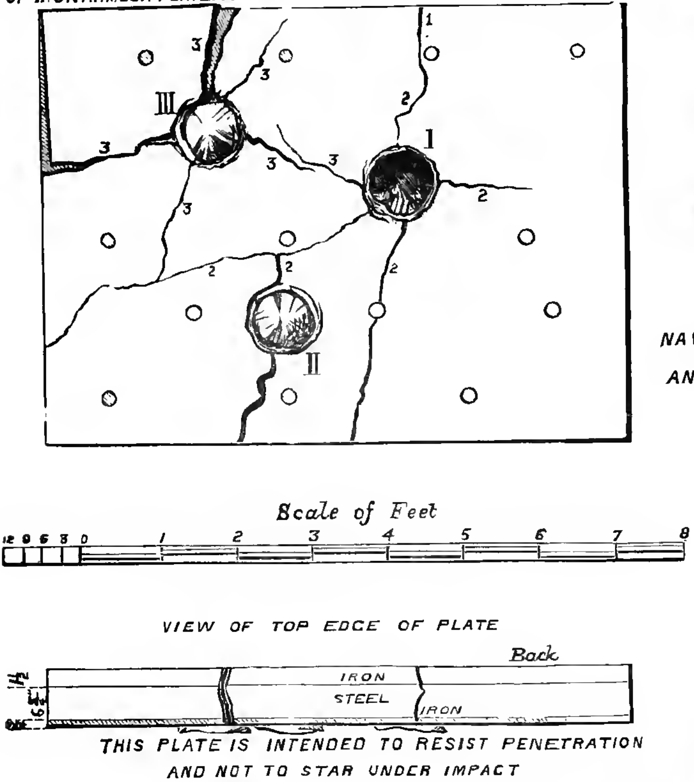
[1] The total energy E here is 1690 foot-tons, $e = 77{\cdot}8$ foot-tons and $t = 9{\cdot}0$ inches. For manufacture *vide* Chapter on manufacture hereafter.

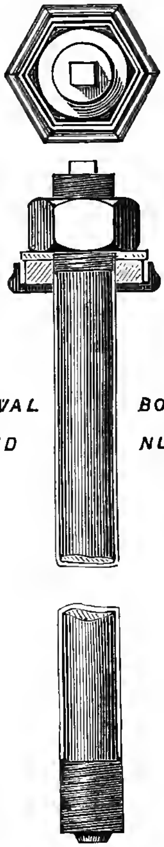
[2] *Vide* "Engineer," August 17, 1877, and December 14, 1877.

9 ins. thick, consisting of a face plate of 5 ins. of steel united to a foundation or back of 4 inches of wrought-iron. The results of the round are shown in Fig. 1, p. 69). The plate exhibited one deep crack, but it was by no means a through crack, extending only to a depth of about 6 inches. The shot was as nearly a match for a 9-inch iron plate as possible; that is to say it was just capable of perforating 9 inches of that material. It can hardly be questioned that this plate offered much greater resistance than iron to a single round. The proportions of steel and iron, however, were not those afterwards found best by the makers, the steel generally constituting one third of the plate.

FIC. 3

COMBINED IRON & STEEL PLATE. HARD STEEL BETWEEN TWO LAYERS OF IRON ARMOUR PLATE. A. WILSON'S. PATENT 8'.0" × 5'.11" × 9" THICK


1
3
3
III
I
2
3
3
3
2
3
2
2
2
II
Scale of Feet
12 9 6 3 0
1
2
3
4
5
6
7
8
VIEW OF TOP EDGE OF PLATE
Back
IRON
STEEL
IRON
THIS PLATE IS INTENDED TO RESIST PENETRATION
AND NOT TO STAR UNDER IMPACT



Experimental steel and steel-faced plates on board the Nettle.

On December 18, 1877,[1] on board the *Nettle*, took place at Portsmouth, a trial of a 9-inch steel plate of Whitworth's and of 3 experimental 9-inch plates, supplied by Messrs. Cammell. The Whitworth plate was much the smallest, it was about 6 feet square, it consisted of soft steel with screw plugs of harder material (*vide* Fig. 1 herewith), at fixed intervals. It was hoped that the steel plugs would both break up the

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[1] *Vide* "Engineer," Author's Report, December 21, 1877.

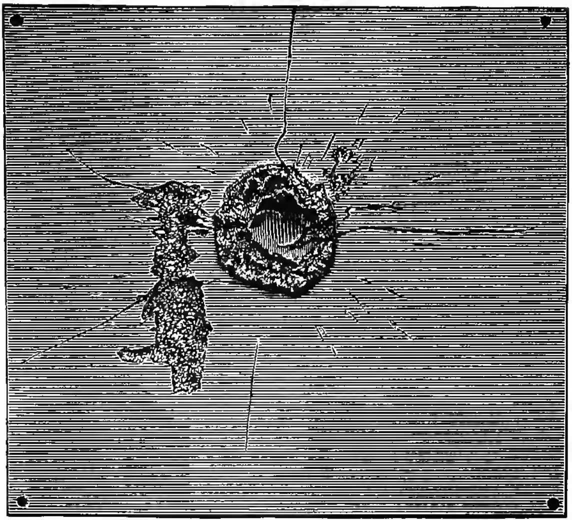
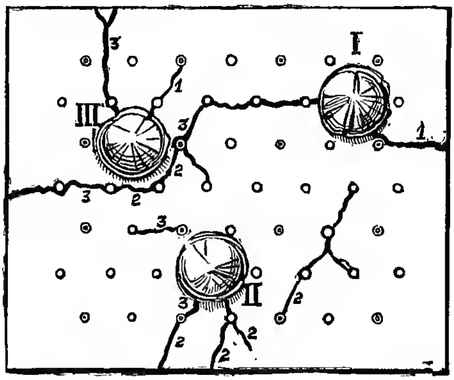


FIG. I FRONT

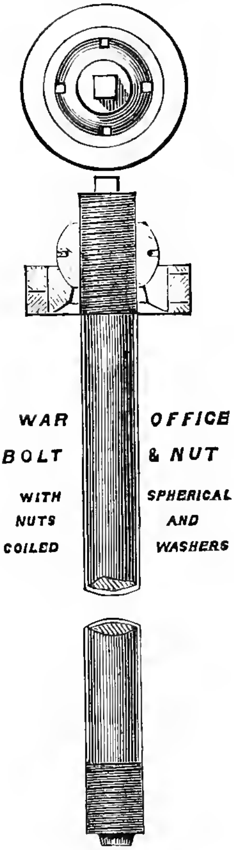
FIG. I
WHITWORTH PLUGGED-STEEL PLATE



VIEW OF TOP OF PLATE

NOTE { NAVAL BOLTS ARE REPRESENTED THUS ●
WAR OFFICE BOLTS " " ○

projectiles and also that any cracks that might be developed in the plate might run to a steel plug and there stop, on the same principle that the further extension of a crack found in a boiler plate is prevented by drilling a hole at the extremity of it. Sir J. Whitworth has acted on the same principle in the construction of other steel plates, it having occurred to him that the best way to limit the cracking in steel would be to "manufacture the cracks" as he expressed it by sub-dividing the armour into small plates. It is easy to understand that a certain measure of displacement might be provided for in this way, and that plates that would not bear distortion without cracking might experience relief, but the question arises as to what shape the work done would take, and how the structure would bear it. Messrs. Cammell had the following plates, whose dimensions are shown in the figures. Sub-carbonized steel, (Fig. 2) containing about 0·13 per cent. of carbon, depending simply on the resisting power of the metal. Fig. 3, a 6¾-inch steel plate, containing 0·57 per cent. of carbon, faced with ¾-inch of iron and built with 1½-inch of iron at the back—9 inches in all. The idea here was to hold the steel from cracking in front and behind. Fig. 4, p. 71, consisted of a hard steel face plate,

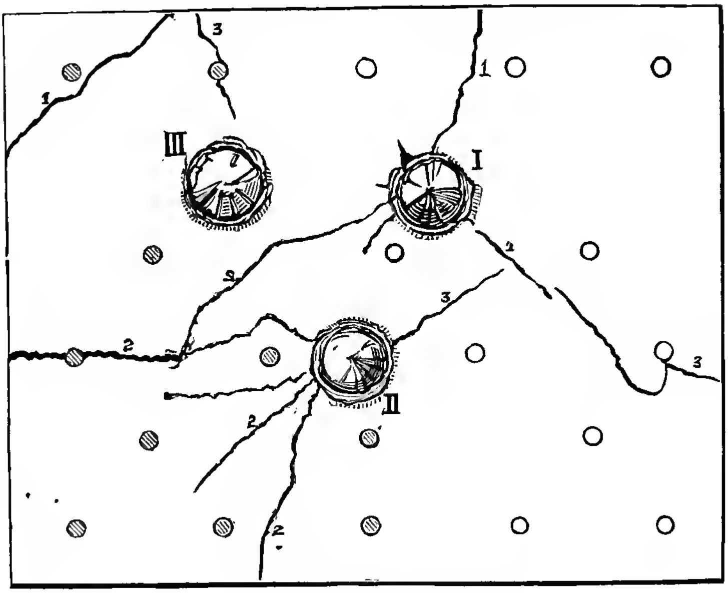


WAR OFFICE BOLT & NUT WITH SPHERICAL NUTS AND COILED WASHERS

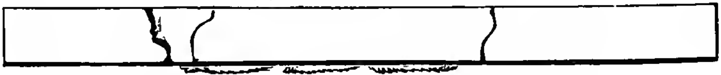
FIG. 2

SOLID STEEL PLATE —— "Subcarburized"

CAMMELL'S PATENT 9.9″ x 7.9″ x 9″ THICK



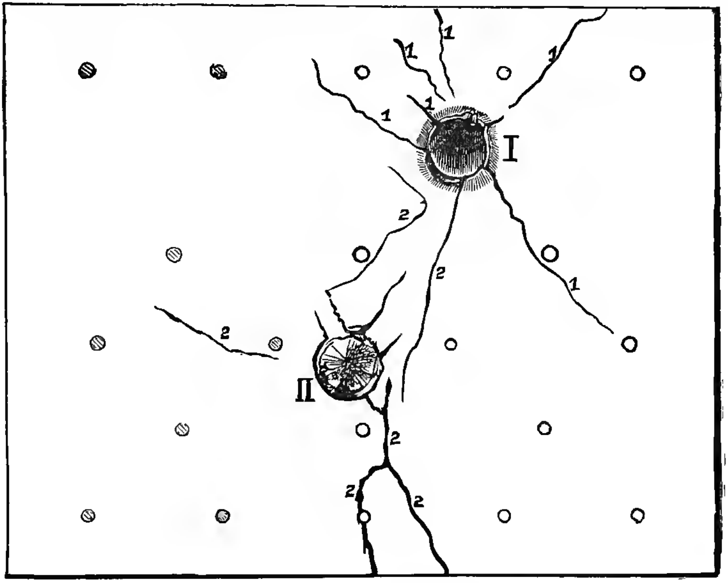
VIEW OF TOP OF PLATE



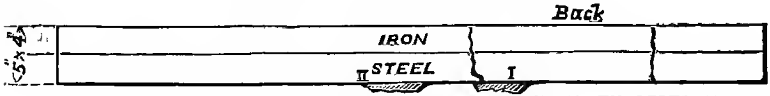
THIS PLATE IS INTENDED TO OFFER A GREATER RESISTANCE TO PENETRATION AND NOT TO STAR UNDER IMPACT containing 0·64 per cent of carbon, 5 inches thick, backed by 4 inches of iron. Here the face might crack, but the plate might be held together by the iron. A wrought-iron plate of excellent quality had been fired at to furnish a standard of comparison. The front and back of this is shown in Figs. 5 and 6, p. 72. The results of the firing are shown generally in the figures. They were not particularly satisfactory. Fig. 4 turned out to be a bad representative of the system, and the shot perforated it, hence only two rounds were fired. As to the others, most Officers would prefer to have the wrought-iron plate here shown on service to either of these for this particular blow, but it must be borne in mind that the Spezia trials had not shown the superiority of steel to iron in the case of a blow which was just a match for the latter, but rather the power of steel to stop a shot which would pass through the iron with a good deal of spare energy. It is probable that Plates 1, 2 and 3, would have stopped a projectile, which would have perforated the iron plate and passed on into the ship which it was intended to protect. This experiment, however, was a crude one, and it is rather given to show the devices that were tried to rival the powers displayed by the steel, even at this time. The further trial of compound plates in England, was conducted in connection with the

FIG. 4

COMBINED IRON & STEEL PLATE. HARD STEEL ON IRON ARMOUR PLATE
A. WILSON'S PATENT 9'.9" x 7'.1½" x 9" THICK



VIEW OF TOP EDGE OF PLATE



THIS PLATE IS INTENDED TO RESIST PENETRATION BY DESTROYING OR BREAKING UP THE PROJECTILE ON IMPACT investigation of the question of the best metal for projectiles by a Sub-Committee under General Inglis, R.E., whose proceedings may next be considered.

FIG. 5

FRONT VIEW OF WROUGHT IRON STANDARD PLATE

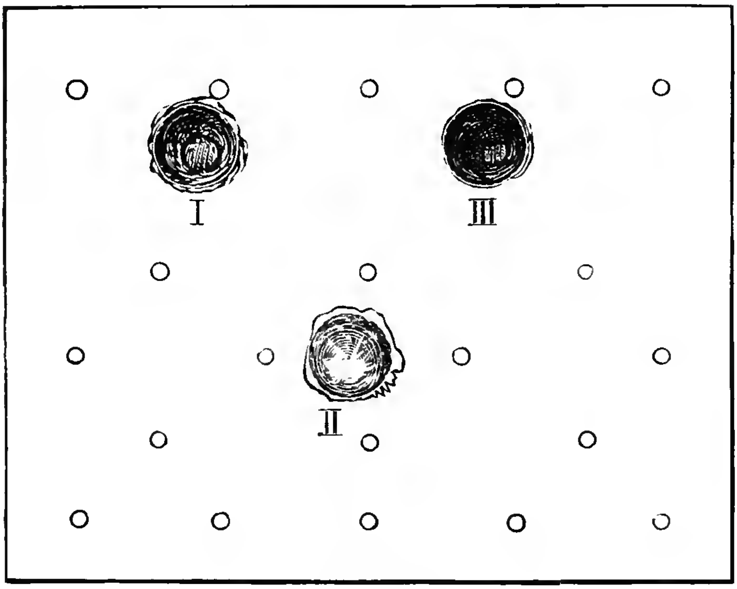
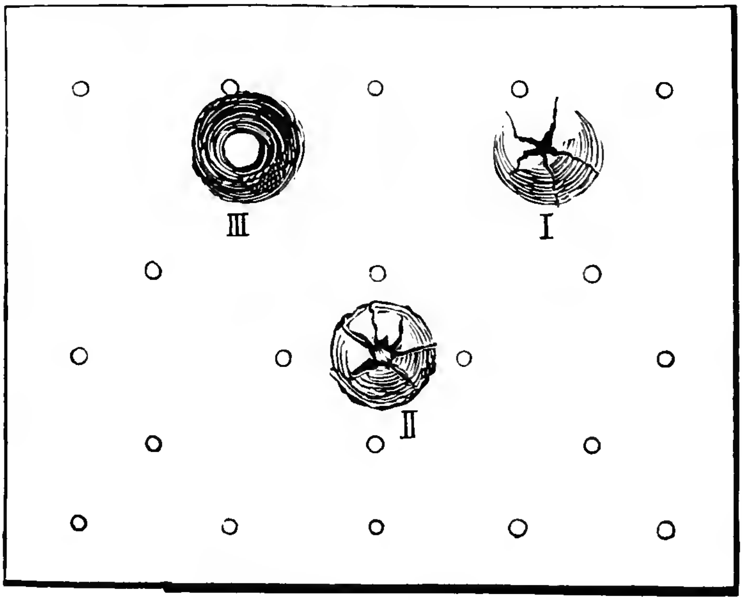


FIG. 6

BACK VIEW OF WROUGHT IRON STANDARD PLATE



CHAPTER VI.

PROCEEDINGS OF THE SUB-COMMITTEE ON PLATES AND PROJECTILES.

A REQUEST was made by the Admiralty on June 5th, 1877,[1] that experiments might be instituted in order to obtain reliable information as to the most suitable metal for armour-piercing projectiles, the following objects being kept in view :—(1) Penetration. (2) Destructive effect of the explosion of a bursting charge on armour and backing. (3) Effect on the interior of armoured structures when completely penetrated. (4) Liability of the shell to break up in the gun.

The improvements in steel and the experiments which had been made with guncotton charges were the causes that led to the series of experiments about to be briefly described. A Sub-Committee of which General Inglis, R.E., was President, was appointed to investigate the matter which was dealt with in the following manner :—

The experiments were divided into two series. (1) To test material for armour-piercing projectiles. (2) To test the best combination of form and material for armour-piercing projectiles.

1st series. (Material). It was decided to obtain projectiles from various makers for the 9-inch M. L. gun, and to fire them with a striking velocity of about 1500 feet, all the projectiles to be of the service pattern for the 9-inch 12-ton M. L. gun, that is, a projectile with studs, and with an ogival head struck with 1½ diameters radius, weight 268 lbs. The projectiles were first to be tried in competition against unbacked wrought-iron plates, each one 4 feet square and 12 inches thick, suspended on short arms fixed in them like trunnions (*vide* Figs. 4–5). These small plates were cut from plates 16 feet long, so that one long plate would cut into four pieces, which would put competing shot on as equal terms as possible. The following projectiles were sent in for competition :—

Chilled iron and steel competitive projectiles.

Chilled Iron. (1) Service shells from store. (2) Royal Laboratory[2] improved. (3) Gregorini iron[3] supplied from Italy, cast into projectiles in the Royal Laboratory. (4) Shells from the Finspong Iron

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[1] Report of Sub-Committee, p. 19, June 22nd, 1880. *Engineer*, April 12, 1878, and August 23rd, 1878.

[2] The metal of these shells contained a small proportion of steel.

[3] This metal is important, having been the material employed for the chilled shot employed in most of the Spezia trials in which this metal was rather differently treated, and proved in its own way to be very good.

Company, Sweden. (5) Shells from Grüson (Germany). (6) Shells from Krupp, Essen.

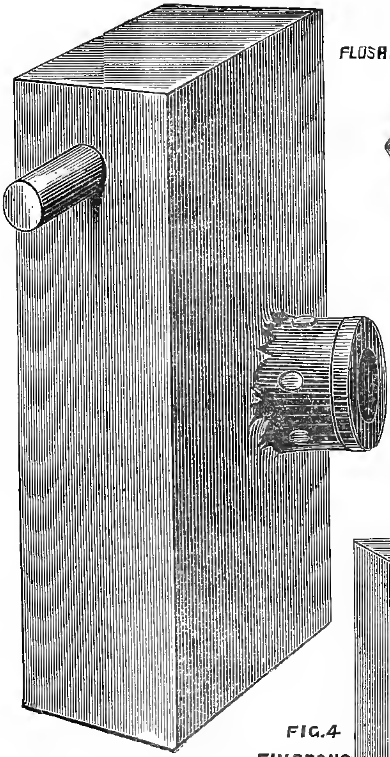
Steel. (7) Shells from the Landore and Siemens Steel Company. (8) Shells from the Terre Noire Steel Company, France. (9) Shells from Messrs. Hadfield & Co. *Shells with cast steel bodies and chilled iron heads* were sent in from (10) Messrs. Vickers & Co., and (11) Messrs. Cammell & Co. *Forged steel shells* were submitted from (12) Messrs. Firth & Co., and (13) Sir J. Whitworth & Co.

The price of the chilled shell was from £26 to £28 per ton, or £2 19s. 7d. to £3 5s. per shell, except Krupp's, which was £39 per ton, and the service shells which were about £10 10s. per ton. The cast steel varied from £6 17s. 7d. to £8 0s. 7d. per shell. The cast steel with chilled points, Cammell's, £5 14s. 8d. per shell, Vickers, £10 per shell, and the forged steels from £8 to £15 each shell.

Great pains were taken to secure equality in conditions in these trials. The wrought iron plates were fired at with the following result:—

Chilled iron shell. (1) The service projectiles were of mottled iron with close grained white chilled heads. They nearly penetrated these 12-inch plates, but broke up as they usually do. (2) The Laboratory improved shells (containing 17 per cent. steel) appeared slightly softer. They got their points through the plates or broke the plates up, with the exception of one bad one; the shells themselves, however, breaking up invariably. (3) *Gregorini* had soft bodies, but the heads were chilled white, in fact, nearly like the service shells. These shells were unfortunate; twice a corner of plate was struck off, once the plate was broken up, and in the two other rounds the penetration was not good. (4) *Finspong* dark grey with white heads, exterior turned, only three shells were fired. The points penetrated the plates and the shells broke up much less than other chilled projectiles. One held together (*vide* Fig. 4, p. 75). (5) *Grüson* chilled over head and body about half way to centre. Three shells were fired, one got its head well through, all broke up, (*vide* Figs. 1, 2, and 3, p. 76). Figs. 1 and 2 do not give a fair sample, but show the behaviour of a bad specimen. (6) *Krupp's,* heads chilled one-third of depth to centre, two shells only fired, penetration not over 11·8 inches, bases of shell broke up.

Of these chilled shell the Laboratory improved were considered to give "decidedly the best results, both as to depth of indent and amount of damage done at the rear of the plate." As to *cast steel shell*—The Terre Noire only held well together, (*vide* Figs. 5 and 6 p. 75), and they set up so much that the Laboratory improved shell were preferred. Of the *cast steel with chilled points,* Vickers was thought to be too soft, but Cammell's were considered better than any of the shells above-mentioned, (*vide* Figs. 8, 9 and 10, pp. 77 and 76). Of the *forged steel,* Firth's were considered soft, but those of Sir J. Whitworth were admirable, some of them standing so well that after passing entirely



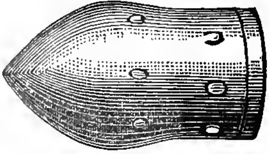

FRONT STUDS CLIPPED OFF FLUSH. REAR STUDS UNINJURED

FIG. 6
TERRE NOIRE PROJECTILE
(STEEL) Nº 2099. AFTER IMPACT

FIG. 5
TERRE NOIRE PROJECTILE
(STEEL) Nº 2093

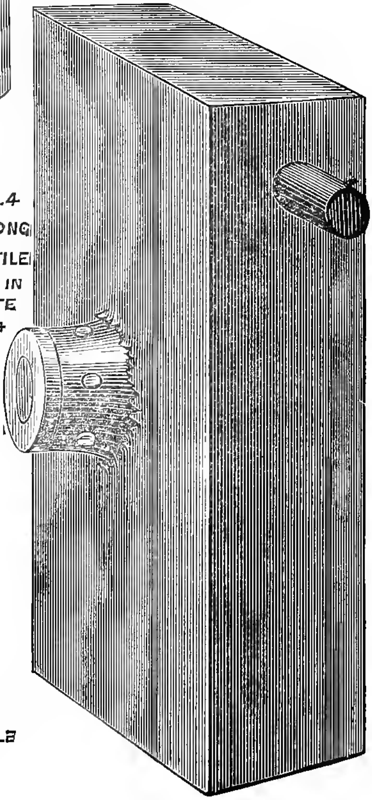


FIG. 4
FINSPONG PROJECTILE
CHILLED METAL IN PLATE
Nº 2094

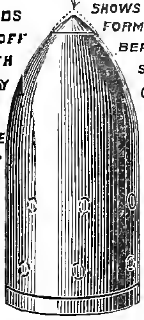

DOTTED LINE SHOWS ORIGINAL FORM OF POINT BEFORE BEING SET UP ON IMPACT
ALL STUDS CLIPPED OFF FLUSH WITH SHELL BODY
NO PERCEPTIBLE SETTING UP OF BODY

FIG. 7
WHITWORTH STEEL PROJECTILE
AFTER PASSAGE COMPLETELY
THROUG 12 IN. PLATE

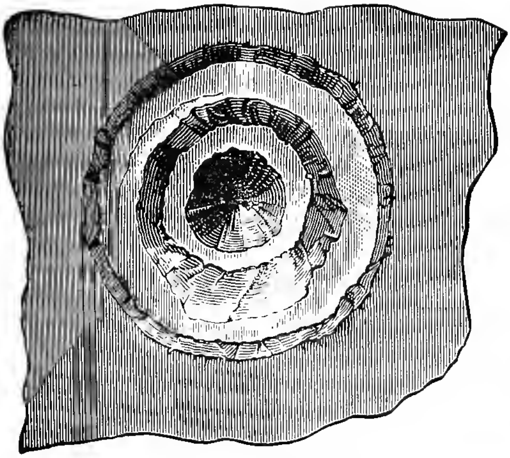


FIG. 1
IMPRESSION IN PLATE MADE BY
GRUSON CHILLED PROJECTILE —— Nº 2095

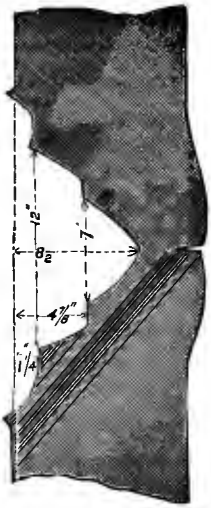
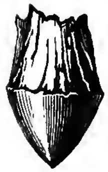


FIG 2
SECTION OF IMPRESSION

FIG. 3



GRUSON SHOT POINT

FIG. 9
PROFILE OF 12 IN. PLATE. AFTER
IMPACT BY CAMMELL'S PROJECTILE —— Nº 2103

VELOCITY
1520 FT
PER SECOND

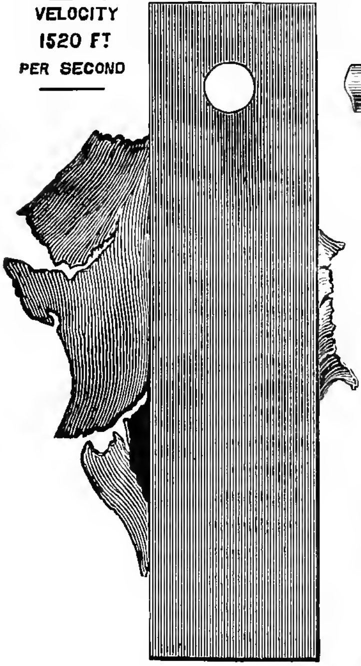


FIG. 10
VIEW OF CAMMELL'S PROJECTILE
—— HEAD WITH POINT BROKEN THRO BACK OF PLATE

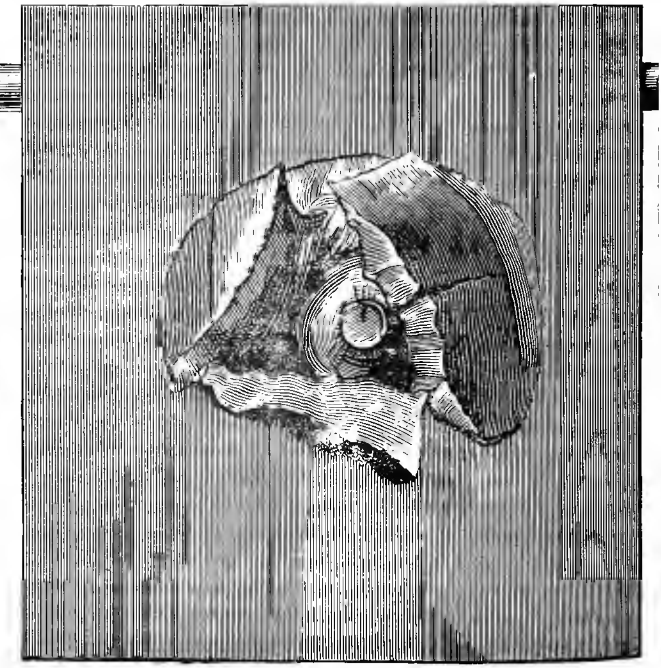
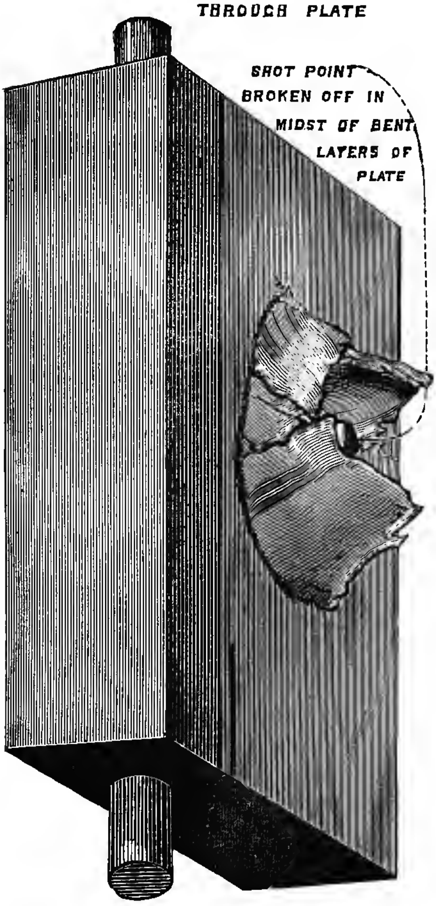


FIG. 8

CAMMELL'S (WILSONS) PROJECTILE
(No. 2097) STEEL WITH CHILLED POINT
SHOWN WITH POINT APPEARING
THROUGH PLATE


SHOT POINT BROKEN OFF IN MIDST OF BENT LAYERS OF PLATE

through the plate, (*vide* Fig. 7, p. 75), they were found uninjured, re-studded, and fired a second, (*vide* Fig. 3, p. 78), and even a third time. The Committee then selected three kinds of projectiles as the best, and continued their experiments with them only, namely, the Laboratory improved chilled projectile, the Cammell cast steel with chilled point, and the Whitworth forged steel.[1]

---

[1] Excellent as this trial was, subsequent experience seems to show that it was imperfect in one respect as it was indeed pointed out by the Committee in their report. The *competition* was confined by the work of *punching holes in soft iron*. It appears to have been assumed that the projectiles that performed this work best would also be the best for attacking the hard armour subsequently fired at. Now, as really hard armour cannot be *punched* but must be destroyed by *racking*, this might perhaps be better done by some of the soft projectiles which set up and penetrated badly but still held together, than by the chilled shell that beat them in the work of perforating soft iron, at the same time breaking up. The investigations of the Committee, even to the end, were too much confined to softer classes of armour. On this, *vide* remarks of Committee on chilled iron, p. 238.

Against iron plates with air spaces between them. Whitworth's forged steel alone held together and penetrated all plates without breaking up, and that even at an angle. The plates were two 2-inch plates inclined at 30° to an 8-inch plate, 4 feet 6 inches in rear of it. Cammell's, when fired direct at two 2-inch plates 4 feet 6 inches in front of 8-inch plate and parallel to it, broke up, the point penetrating 6·75 inches into the 8-inch plate. Firth's shell was fired at an angular air space target like Whitworth's; the shell made a hole through all, but remained broken in the last plate. Fig. 4 shows the back of a

FIG. 3

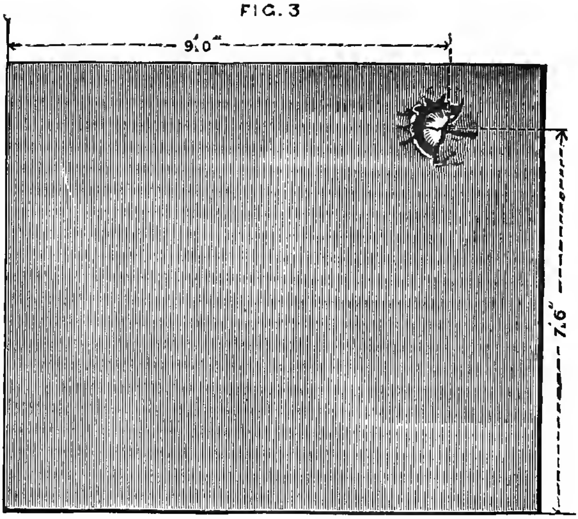
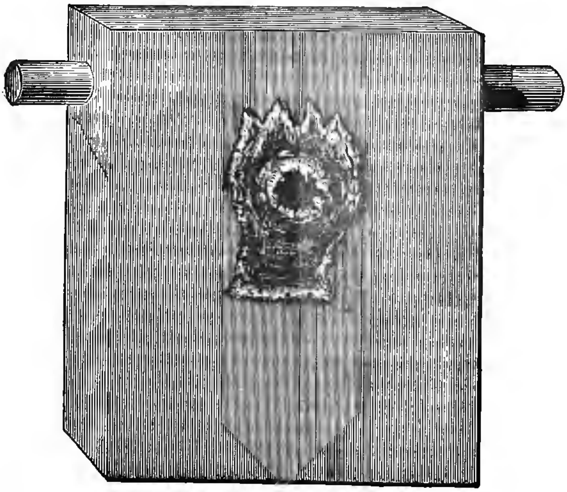


FIG. 4



wrought-iron plate after perforation by a Cammell-Wilson cast-steel shot with chilled iron point, fired on July 24th, 1877; striking velocity 1440 feet. The plate, however, had suffered from being fired at already.

Further experiments with selected projectiles.

The further experiments of this Committee consisted in firing the selected classes of projectiles, with variations in form and make, at wrought-iron plates, either single or with air spaces between them, and at steel-faced wrought-iron plates directly and obliquely. The chief changes in form and make consisted in getting rid of the studs, a rotating gas check being employed on the base of the projectile, and in trying various forms of head, that is, flat-heads, ogival points struck with radii from 1·5 to 3 diameters, and one or two specially pointed shot.

It was found that fired directly against a 14-inch wrought-iron plate a Cammell, with a specially sharp point was best, then came Whitworth, Laboratory, and Cammell with two diameter heads. Owing to a failure in armour plates, these were the sharpest points tried, among many blunter ones, the Whitworth flat-headed, in order of merit, came last of all. This implies that for direct penetration into iron a sharp point is best.[1]

Firing at 12-inch wrought-iron plates at angles varying from 30° to 37° 4′ with the normal (60° and 52° 56′ with the face of the plate), the Laboratory improved was rather better than the Whitworth. In each case the 2 diameter head beat the 1·5 diameter head. All projectiles broke up on oblique impact, except 2 Whitworth forged steel shells out of 5 fired. At the same plate at 29° 30′ to 31° 30′ with the normal (60° 30′ and 58° 30′ with the face of the plate) the Laboratory 2 diameter head was the best, the other 2 diameter heads were beaten by the corresponding ones of 1·5 diameter. The Whitworth flat-head was about midway in merit among the projectiles.

When the projectile was not a match for the plate, the projectiles bit at 30° with normal (60 with plate); at more oblique angles (37° 4′ with normal) scoops only were made. When the shot was more than a match for the plate it bit at a more oblique angle, namely, at 35° to 36° with the normal, at 40° (50° with face of plate) only a scoop was made.

In direct firing[2] against steel-faced plate 4 feet square and 12 inches thick, Cammell's 2 diameter head shell obtained the best penetration, namely, 18 inches. Whitworth's were nearly as good. None of the projectiles held together. Whitworth's broke into the fewest pieces. The only chilled shell fired broke up with a penetration of only 2 inches.

In oblique firing at steel-faced armour, 10 inches thick, consisting of 4 inches of steel on 6 inches of iron, striking at an angle of from 25° to 27° with the normal, (65° to 63° with the face of the plate).

---

[1] Sir W. Palliser, on a small scale, found that a steel bullet fired from a rather large bore small arm (the Minié), with a point struck with 6 diameters radius, gave exceptionally good penetration. This is not surprising. Plates are torn open generally, the tear commencing in a cross or star at the back of the plate, opposite the point of the shot which is able to reach the spot, and act directly on it more easily in the proportion in which the point is made sharper.

[2] Report of Sub-Committee, p. 11.

Cammell's steel shells with chilled point, 2 diameters radius, were slightly the best, but they broke up even against comparatively weak armour. *The Committee arrived at the following conclusions:—*

Conclusions of Sub-Committee.

As to material. The Whitworth forged steel gave the best results when fired direct against wrought-iron, and they alone would have carried a bursting charge behind the armour.

The Cammell shells (steel with chilled point) produced most effect against steel-faced armour, both indirect and oblique fire, but broke up. Chilled iron gave the best results when fired obliquely against iron, but invariably broke up both on direct and oblique impact. Whitworth forged steel shells striking with a velocity of from 1700 to 2000 feet were only slightly set up, none were fractured (against wrought-iron). One Cammell forged steel shell held together after striking a 16·5-inch wrought-iron plate.

"The Committee think it important to point out that they have had no means of arriving at any conclusion as to the best form and material for projectiles, with which to attack the chilled-iron armour, which is being adopted by Foreign Powers particularly for Coast Batteries."

On the whole, the Committee found—(1) Steel projectiles absolutely necessary for the attack of steel-faced armour. (2) In mere penetration in wrought-iron, steel and chilled are nearly equal, chilled being slightly better obliquely. (3) If fired direct even against wrought-iron, not beyond the power of the gun, with high velocity, chilled shells almost invariably break up. Cast-steel may, if improved, eventually hold together. Forged steel may be implicitly trusted to remain unbroken. (4) The metal[1] of the Laboratory improved shells is very superior to that previously employed.

With regard to the form, studs were recommended to be abolished, and an ogival head with 2 diameters radius was preferred on the whole for both chilled and steel shot. As to the relation of diameter of shot to weight, the Committee recommend something heavier than that shown by the relation $\frac{W}{d^3} = 0{\cdot}364$.[2]

Compound (steel-faced) armour undoubtedly was found to possess the great advantage of shattering chilled projectiles, and causing even forged steel ones to set up and to deflect projectiles striking at an angle well, but the Committee considered that these results were *"only to be relied upon when the plate is beyond the power of the gun."*

In direct fire, a good compound plate between 9 and 10 inches thick, was found to be about equal to a good 12-inch wrought-iron plate, for a single blow; under repeated blows, it is decidedly inferior to the wrought-iron plate. In this comparison, steel projectiles are supposed to be used against the compound plate, while either chilled or steel may be used against the wrought-iron. In oblique fire, the 10-inch compound plate was broken up by blows amounting to 554 foot-tons per square foot. The 12-inch wrought-iron plate bore 650 foot-tons per square foot, and might, it was expected, bear blows amounting to about 992 foot-tons in all.[1]

---

[1] Containing 17 per cent. of steel.

[2] This has more recently been brought to $\frac{W}{d^3} = 0{\cdot}42$, *see* Report, p. 15.

Finally the Committee made the following recommendations :—

Recommendation.

1. That all chilled battering projectiles should be of the kind tested as "Laboratory improved."
2. That all battering projectiles should have heads struck with a radius of 2 diameters.
3. That the question of a delay-action fuze to be used with guncotton be further investigated.
4. That a certain proportion of forged steel shells be issued, the proportion depending on the results of recommendation No. 3.
5. That cast steel projectiles be not adopted unless greatly improved.
6. That in armour-piercing shells, capacity for bursting charge be considered as of less importance than strength of head and walls.
7. That the proportion of weight to calibre in armour-piercing shells be investigated with larger guns.

Three questions may be noticed separately—(1) The employment of guncotton. (2) The trial of a wrought-iron cap on the point of shot. (3) The investigations as to weight and velocity carried out with the Armstrong 6-inch and 8-inch new type guns.

(1.) The employment of guncotton is specially important because the power to carry fire through armour appears at present to depend on it. As noticed above, forged steel alone give promise of holding together while passing through thick armour, even of wrought-iron, and forged steel shells refuse to be burst by gunpowder. Guncotton, burst in the ordinary way, has disappointed expectation in Italy. It is however difficult to provide for its detonation in a way that does not endanger the gun. On this the Committee report that they had not sufficient experience to speak positively. The delay-action fuze, tried by them, enabled shells to carry fire through armour up to their power, and a fuze being found which detonated the wet guncotton charge of a shell striking armour with a velocity not exceeding 1554 f.s. Further investigations as to a delay-action fuze were recommended. Figs. 1 and 2, p. 240, show the effect of a Whitworth steel shell fired with a bursting charge of 4 lbs. 2 ozs. at a 12-inch wrought-iron plate. The shell refuses to break up, the gas escaping at the base plug hole. The shell is expanded against the plate, thus the latter is cracked, while the shell, instead of passing through the plate, is held.

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[1] Amounting to 3093, 3023 and 4614 foot-tons per ton of plate respectively for compound 10-in. and wrought-iron 12-inch actual and estimated tests, assuming each to weigh 0·215 tons per cubic foot.

FIG. 1

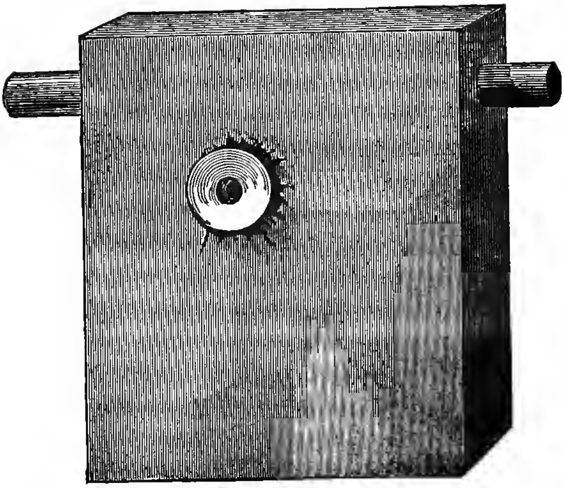
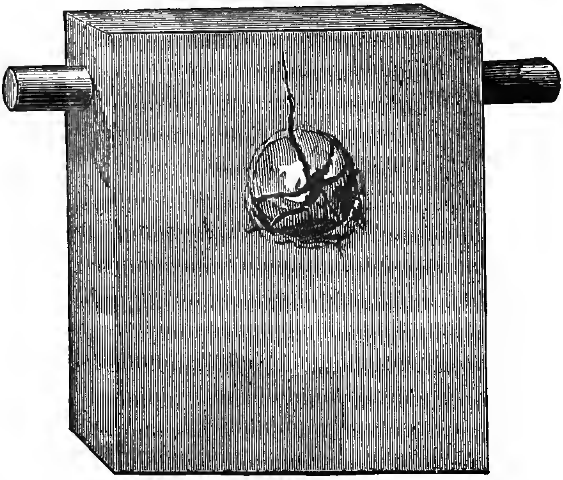


FIG. 2



Wrought-iron Cap on point of projectile.

(2). The trial of a wrought-iron cap[1] on the point of the projectile arose from the fact being discovered that a steel-faced armour plate lost its power of breaking up chilled shot, its resistance being diminished to less than that of wrought-iron, by simply placing a 2½-inch wrought-iron plate over the steel face of the plate. A Palliser projectile doing more work on the compound plate with this addition than without it, and the effect on the shot itself being quite different, General Inglis concurred with Captain English in thinking that a similar result might be produced, and a chilled projectile kept from breaking up by applying a wrought-iron cap to the point when attacking steel-faced armour. This was tried. The effect of the first shot so fired encouraged further investigation of the subject, but further trial showed that no advantage was gained by the cap.

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[1] Pages 43 and 125, see Report, p. 43, Report of Sub-Committee, see index, p. 175. This experiment was suggested by Major English.

Investigation of law of perforation.

(3). The investigations made by the Sub-Committee as to the effect of projectiles fired at armour with a sufficiently great variation in velocity to determine some law as the power of projectiles to perforate under various conditions, can only here be dealt with briefly. The Armstrong B. L. 6-inch and M. L. 8-inch new type[1] guns which were placed at the service of the Committee, achieved so high a velocity that experiments could be made with greater variation in conditions than hitherto, the striking velocities varying between 836 feet and 2212 feet per second. With the 6-inch gun which was first fired with the following objects—(1.)[2] To determine the penetration of 6-inch projectiles of uniform weight with different velocities. (2) To determine the penetration with a uniform energy, whether made up of high velocity and a light projectile, or of a low velocity and a heavy projectile.

Experiment 1. The first object was to arrive as exactly as possible at the velocity necessary to perforate unbacked and unsupported wrought-iron plates varying in thickness from 4 inches upwards, with an 80 lb. shell with a 1·5 diameter ogival head. A 12-inch plate is more than proof against this shot at the muzzle[3] a 6-inch plate was proof against the same at 2820 yards, and a 4-inch at 6000 yards.

Experiment 2. To determine penetration with uniform energy, made up of weight, and velocity, in varying proportions. Shells of 60, 80, and 100 lbs. weight were used, and 8-inch, 12-inch, and 13-inch plates. The total energies for these plates being 1080 foot-tons, 1800 foot-tons, and 1900 foot-tons respectively. The 80 lb. shot gave the best result, then the 100 lb. and the 60 lb., the worst result. It was not found, in fact, that a uniform energy gave a uniform result, and without basing too much on a limited series of rounds (35 in all) the Committee considered that it was shown that a 60 lb. shell was too light to develop the full battering power of this gun.

The trials with the 8-inch gun had the following objects in view :[4]—

(1.) *To determine penetration with a uniform weight of shot and varying velocities.* (2.) *To determine penetration with a uniform energy, made up of weight and velocity in different proportions.* (3.) *To compare penetrations of shells with heads struck with radii of 1·5 and 2·0 diameters, other conditions being the same.* 54 rounds were fired, 43 being with chilled projectiles and 11 with forged steel. Some of the chilled projectiles held together on impact, but the highest velocity at which they did so was 1337 feet. This gun was capable of penetrating about 14·7 inches of iron at the muzzle, with a velocity of 2010 feet.[1] As to weight, it appeared that with equal striking energy a shell of 132·5 lbs. was inferior to shells of 182·2 lbs. and 232·5 lbs. The two latter produced nearly equal effects. The 2 diameter head proved better than that of 1·5 diameters.

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[1] *Vide* D. of A. "Proceedings," 1879, Vol. 17, p. 188.

[2] *Vide* p. 34, "Report."

[3] With a striking velocity of 2030 and a weight of 80·25 lbs. E (striking energy) is 2294 and e (energy per inch) 121·7 and t (thickness that would be perforated) 11·57. The projectile got its point through.

[4] *See* "Report," p. 37.

The experiments with the 6-inch and 8-inch guns led to the conclusion that with these guns $\frac{W}{d^3}$ ought at all events not to be below 0·364. Results were not always good when $\frac{W}{d^3}$ reached 0·47, perhaps owing to the length of the shot causing it to set up.

With a 13-pr. gun it was found that projectiles had nearly the same effect if their energy was the same, whether $\frac{W}{d^3} = 0{\cdot}508$ or $0{\cdot}364$, but experiments were not made with lighter projectiles.

The following table shows the results obtained with the 8-inch M. L. gun:—

Résumé of Experiments against Iron Plates with 8-in. Muzzle-loading Guns.[2]

No. of round.	Charge.		Shot.		Velocities. Feet per second.		Energies, foot-tons.			Thickness of plates.	Remarks.
	Weight.	Description.	Weight.	Description.	Muzzle.	Striking.	Muzzle total.	Striking total.	Per inch of shot's circumference.		
	lb.		lb.							inches.	
1	24·5	R.L.G	162·5	Head 1·5 diameter. Chilled shell.	1035	1023	1355·6	1324·4	53·06	6	Through easily.
2	20	"	"	"	931	922	1096·8	1075·8	43·10	6	Nearly through. Penetration 12·5 ins., apparently nearly through; shot entire and uninjured
3	21	"	"	"	941	932	1120·5	1099·2	44·0	6	Nearly through. Penetration 1·6 in., but little difference from the last. Shell entire and uninjured.
4	21	"	"	"	972	962	1193·2	1171·1	46·9	6	Through. Projectile broken.
5	31	"	"	"	1176	1157	1750·2	1694	67·8	8	Through.
6	29	"	"	"	1142	1123	1650·5	1596	63·9	8	Practically through.
7	46	pebble	"	"	1320	1296	2205·0	2125·5	88·0	10	Penetration 9·4-ins.
8	54	"	"	"	1438	1411	2617·1	2519·5	100·9	10	Penetration 12-ins.
9	57	"	"	"	1497	1468	2843·0	2727·1	109·2	10	Through. Head of shell with band lying in rear of plate.
10	68	"	"	"	1679	1648	3567·4	3437·0	137·7	12	Practically through. Head and first band through plate, rest sticking in plate; but rear of projectile 2 ins. within face of plate.
11	83	"	"	"	1894	1860	4539·5	4376	175·4	(12+2) 14	Penetration 14-ins.
12	88	"	"	"	1987	1950	4096·2	4812	192·7	(12+2) 14	Through.

[1] *See* "Report," p. 43. The weights of shell of *the same form* will vary with the cube of their diameter for simple mathematical reasons. Hence, $\frac{W}{d^3}$ expresses the factor on which the variation in weight, or as it is sometimes termed, the sectional density depends. In solid shot of the same form of head any variation must be due to variation in length. In shells the size of interior cavity of course affects it. Shape, and even nature of metal in some cases may affect it.

[2] This forms part of the remarkable series of experiments on which the systems of calculation in Chap. III. were based.

Résumé of Experiments against Iron Plates with 8-in. Muzzle-loading Guns.

No. of round.	Charge.		Shot.		Velocities. Feet. per second.		Energies, foot-tons.			Thickness of plates.	Remarks.
	Weight.	Description.	Weight.	Description.	Muzzle.	Striking.	Muzzle total.	Striking total.	Per inch of shot's circumference.		
	lb.		lb.							inches.	
13	95	〃	〃	〃	2061	2024	5375·4	5184·1	207·6	(12+2+2) 16	Penetration 12·4 ins., Grazed on a plate lying flat before striking. Plate at an angle of 20 degrees.
14	100	〃	〃	〃	2141	2101	5800·8	5586·1	223·8	16·5	Practically through. Penetration 20·95 ins.
15	19	R.L.G	〃	〃	892	884	1004·7	988·9	39·6	6	Penetration 10·8-ins. Head 4·8-ins. in rear of plate. Shell broken into big bits.
16	16	〃	〃	2 diameters.	velocity lost.		—	—	—	8	Penetration 7·85-ins.
17	19	〃	〃	〃	888	878	993·3	975·5	39·1	6	Penetration 7·9-ins. Shell entire at foot of plate.
18	29	〃	〃	1·5 diameter.	1117	1098	1528·6	1525·7	61·1	8	Penetration 9-ins.
19	29	〃	〃	2 diameters.	1127	1108	1553·8	1553·6	62·2	8	Penetration 13-ins.
20	31	〃	132·5	1·5 diameter.	1342	1308	1654·7	1571·9	62·9	(6+2) 8	Penetration 9·5-ins., point 1·5-in. in rear of plate.
21	27·5	〃	232·5	〃	975	969	1532·5	1513·8	60·6	(6+2) 8	Through. Head hit another plate after passing through and flew into dust.
22	110	pebble	182·5	〃	2332	2190	6304	6069·3	243·1	(14+2+2) 18	Penetration 18-ins. Shell passed through the 2-in. plates breaking up the 14-in. plate.
23	20	R.L.G	〃	〃	931	922	1097	1076	43·1	8	Nearly through. Point of head through. Moulded off to 2·6-ins.
24	19	〃	〃	〃	898	899	1020	1000	40·0	8	Penetration 7·9 ins. Shot entire.
25	19	〃	〃	〃	883	875	987	968·8	38·7	6	Penetration 12·5-ins., 6·5-ins. behind back of plate. Shell unbroken, but cracked; moulded off to 1·25-ins.
26	55·5	pebble	〃	〃	1458	1421	2113	2554·6	102·0	10	Through. Plate broke; shot in small pieces.
27	56	〃	〃	〃	1470	1441	2735	2627·0	104·9	(special) 10	Shell passed clean through; hit target in rear and broke into small pieces.
26	51	〃	〃	〃	1426	1399	2573	2476·1	98·9	(special) 10	Clean through. Shell broke as before; gas check and all through.
29	50	〃	〃	〃	1361	1335	2344	2254·7	90·05	10	Penetration 13·05-ins., gas check and body in four pieces in front; point of shell 3·05-ins. behind back; head, &c., in hole.
30	50	〃	〃	2 diameters.	1363	1337	2351	2281·5	90·3	10	Penetration 16·05-ins.; whole of shell in hole; point 6·05-ins. behind.
31	111	〃	〃	1·5 diameter.	2256	2212	441	6190·1	247·2	(solid) 16·5	Shot apparently not good; plate fell on to its face; front moulded off to 2·6-ins.
32	29	R.L.G	〃	〃	1120	1102	1587	1536·4	61·4	(6+2) 8	Penetration 10·45-ins. rear; moulded off to 3·4-ins.; gape 4-ins.
33	31	〃	132·5	〃	1320	1288	1601	1519	60·7	(6+2) 8	Penetration 9·32-ins.; shot remained sticking in; moulded off to 2-ins.
34	27·5	〃	232·5	〃	946	939	1443	1421·1	56·8	(2+6) 8	Penetration 8-ins.; plate broken up and much thrown about.
35	50	pebble	182·5	〃	1343	1317	2282	2194·3	87·64	12	Penetration 9·45-ins.; point as shown and rest in fair-sized pieces.
36	53	〃	132·3	〃	1554	1513	2215	2102·6	84·0	12	Penetration 8·3-ins.; body in fair-sized pieces.
37	48	〃	232·5	〃	1217	1201	2368	2324·7	92·9	12	Struck near former hole, and turned into it.

Résumé of Experiments against Iron Plates with 8-in. Muzzle-loading Guns.

	Charge.		Shot.		Velocities. Feet. per second.		Energies, foot-tons.				
No. of round.	Weight.	Description.	Weight.	Description.	Muzzle.	Striking.	Muzzle total.	Striking total.	Per inch of shot's circumference.	Thickness of plate.	Remarks.
	lb.		lb.							inches.	
38	45	„	„	„	1167	1152	2196	2139·4	85·6	12	Penetration 9·5-ins.; last round repeated; plate broke in two; shell broke mostly in large pieces; bulge at back ·83-ins.
39	28·25	R.L.G	„	„	1002	994	1619	1593·0	63·8	(6+2) 8	Penetration 10·75-ins., head in two pieces in hole; moulded off to 2·1-ins.
40	29·75	„	182·5	„	1157	1137	1691	1636	65·5	(6+2) 8	Body of shell in large pieces; small piece of head through; plate moulded off to 2·7-ins.: gape 6·25-ins. × 6·25-ins.
41	31·75	„	132·5	„	1381	1345	1752	1662	66·4	(6+2) 8	Penetration 9·75-ins.
42	68	pebble	182·5	Steel shell. 1·5 diameter head.	1662	1631	3496	3366	134·6	12	Through. Plate broke into two pieces through hole. Shell unbroken. Diameter at shoulder before firing, 7·97-ins.; after firing, 7·99-ins. Diameter at rear band before firing, 7·93-ins.; after firing, 7·932-ins.
43	66	„	„	„	1988	1951	5001	4817	192·9	(2+12) 14	Through. Broke up plate. Shell struck a plate in rear and broke up.
44	28·23	R.L.G	232·5	Chilled. 1·5 diameter. head.	1006	998	1631·6	1605·3	64·3	(8+2) 8	Through. Shell broke up; head as shown, body in fair-sized pieces; 6-in. plate hard and broke up into three pieces.
45	88	pebble	182·5	Forged steel. 2 diameter head.	1970	1934	4911·2	4732·0	189·7	14	Through. Shell broke into seven pieces; plate broken through old shot-hole into three pieces.
46	83	„	„	„	1874	1840	4444·2	4283·2	171·7	„	Through. Shell broke into nine pieces; gas check entire; plate broken into three pieces.
47	83	„	„	do. Cammell 1·5 diameter head.	1889	1855	4515·6	4353·3	174·5	„	Nearly through. Shell broken, and plate broke up into three pieces.
48	90	„	„	do. Firth, No. 53. 1·5 diameter head.	1961	1928	4966·2	4702·7	188·5	8	Through. Shell through plate and broke up in sand, penetrating 10 ft. into sand.
49	31·25	R.L.G	132·5	do. No. 49. 1·5 diameter head.	1372	1336	1729·5	1639·4	65·7	(2+6) 8	Point 1·27-in. through. Shell entire, but cracked. Penetration 9·27-ins.
50	29·75	„	182·5	do. No. 54. 1·5 diameter head.	1142	1123	1650·4	1595·5	64·0	(2+6) 8	Through easy. Shell entire, striking target in rear, and making impression at head without point.
51	28·25	„	232·5	do. No. 57. 1·5 diameter head.	988	979	1567·4	1544·7	61·9	„	Through. Shell after penetration hit No. 40 target in rear sideways and broke up.
52	83	pebble	182·5	do. Cammell 2 diameter head.	1890	1839	4520·4	4278·5	171·5	8	Through. Shell unaltered, passing through corner of sand butt.
53	114	„	„	Chilled, No. 69.	Shell	broke	up in	gun.	No re	cord.	Pressure in chamber 38·4 tons per square inch.
54	111	„	„	Cammell's steel hardened in oil. No. 60.	2256	2212	6440·7	6190	248·1	(solid.) 16½	Gape about 3-ins. Mould off back of plates, 3·7-ins.; over, 33-ins. by 30-ins. Shell ·2-ins. beyond back of plate, base being ·5-in. from face of plate. Shell unbroken, but set up 1·8-in. of length. Penetration 16·75-ins.

CHAPTER VII.

EXPERIMENTS CONTINUED.—HARD AND SOFT ARMOUR.

The series of experiments made by General Inglis' Sub-Committee has been given without interruption. The report was sent in 1880, and in the meantime other experiments had been made, which may be noticed.

Dutch Experiments with steel and chilled projectiles.

A report[1] printed by the Dutch Government on a trial against armour of projectiles supplied by Ekman—of Finspong—Krupp, and Grüson, took place at Scheveningen, on June 16th, 1879, has a special interest from the fact that the projectiles were all fired with a reduced velocity, calculated purposely to give bare penetration as nearly as possible. In the English trials with Armstrong 8 and 9-inch guns the

FIG. 1

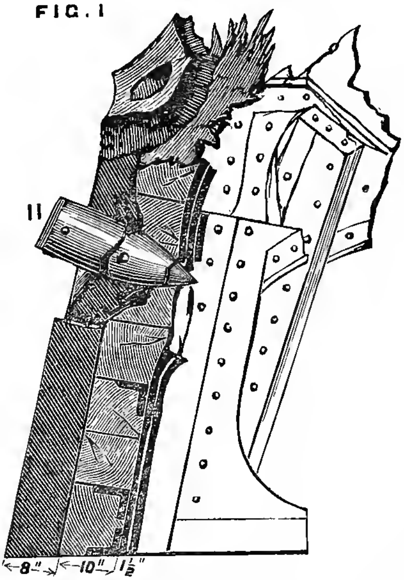
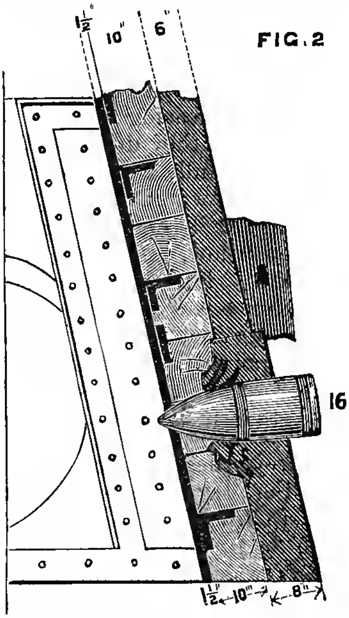


FIG. 2



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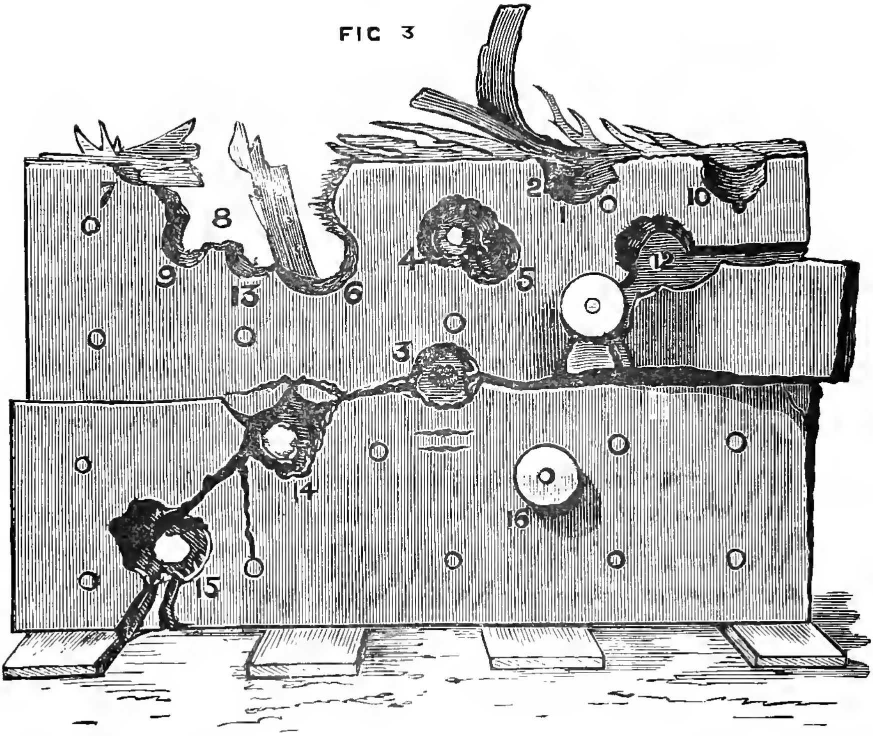
[1] *Vide* "original Dutch Report," dealt with in Engineer, Oct. 15th 1880, p. 278. See also D. of A. "Proceedings," Vol. XVII, p. 38.

FIG 3



same idea was carried out, beginning at about the same thickness of plate, but increasing up to a very high standard. The Dutch experiments, if they did not embrace an ambitious programme, were at all events carefully carried out, and are therefore instructive. The plate fired at is shown in Figs. 1, 2, and 3. It consisted of a section of the English Bellerophon target, namely, iron plates of 6-ins. and 8-ins. above and below, (as shown in Figs. 1 and 2) on 10-in. of teak, with 1½-in. skin. For this, a penetrating figure of 60 foot-tons per inch circumference was found to be sufficient for the upper portion, and 93 foot-tons per inch circumference enabled the projectile shown in Fig. 2 to get its point through the inner skin of the lower portion. The guns employed were a cast iron and a steel gun, each of 24 centimetres calibre—that is 9·45-ins. The range was 500 metres—547 yards.

The projectiles supplied were as follows:—From Ekman, *chilled iron*—(*vide* Fig. 4) of two sizes, namely, 2·6 calibres long, weighing 147·75 kilogs. (325·73 lb.,) and 2·8 calibres long, weighing 152·34 kilogs. (335·85 lbs.) These were chilled nearly to the centre in the head, and the body was left unchilled—*vide* Fig. 4. From Grüson, *chilled iron*—*vide* Fig. 5—of two sizes, namely, 2·6 calibres long, weighing 149·65 kilogs. (329·93 lbs.) and 2·8 calibres long, weighing 153·85 kilogs. (339·18 lbs). These were chilled to a certain depth over both head and body, as shown in Fig. 5. From Krupp, *steel*, 2·8 calibres long, weighing 161 kilogs. (354·94 lbs).

FIG. 4.

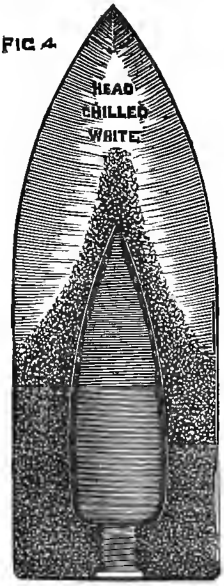
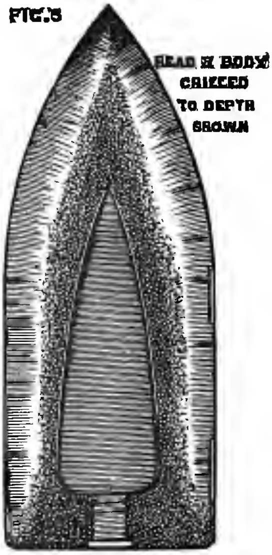


FIG. 5.



More was expected from the steel projectiles than the chilled ones. They were heavier, and were fired with a higher charge at the lower portion of the target from the steel gun, which was polygrooved, the projectiles being rifled by means of copper rings near shoulder and base, as seen in projectile in Fig. 2, whereas the chilled projectile had studs, being fired from the cast-iron gun at the upper portion of the target. In all, seventeen rounds were fired, namely, four heavy and one light of Ekman's, five heavy and three light of Grüson's, and four of Krupp's. The table at p. 90 gives the details.

The following conclusions were arrived at as regards the calculated penetration, namely, that a projectile discharged from the cast-iron gun, with a velocity of 373 metres, or 1,224-ft., would pierce the 6-in. plate at about 1,800 metres (1,969 yards) range; and a heavier projectile from the steel gun, fired with a velocity of 472 metres (1,549-ft.) would pierce an 8-inch target and backing at about 1,800 metres (1,969 yards).

As regards the projectiles, none of the Ekman (Finspong) chilled iron projectiles were broken up on impact, except that the point of one was broken off to the length of 142-mm. (5·6-in.) The remainder of the projectiles underwent no alteration in form beyond setting up to the extent of 6-mm. (0·236-in.) in length. Of the eight Grüson chilled iron projectiles, seven broke up into a great many fragments, while one, which remained entire, showed a crack along the tapering portion about the shoulder of it, but was set up in length only 2-mm. (0·079-in.) The Krupp steel projectiles all remained entire. They underwent a slight deformation, setting up longitudinally to the extent of from

22-mm. to 28-mm. (0·866-in to 1·102-in.) while above the shoulder the diameter increased to the extent of from 1·5-mm. to 2·5-mm. (0·059-in to 0·098-in.); also all the points for a length of 16·5-mm. to 21·5-mm. (0·64-in. to 0·84-in.) were deformed. The Swedish projectiles of Ekman were considered very superior to those of Grüson. The Committee found it difficult from these experiments to say whether the steel showed a superiority sufficiently decided to justify their high price as compared with the chilled projectiles.

With regard to this report, it may be remarked that the behaviour of the Finspong projectiles to a certain extent agreed with the results obtained in English competitive trials—that is to say, the Grüson's projectiles were harder than the Finspong.

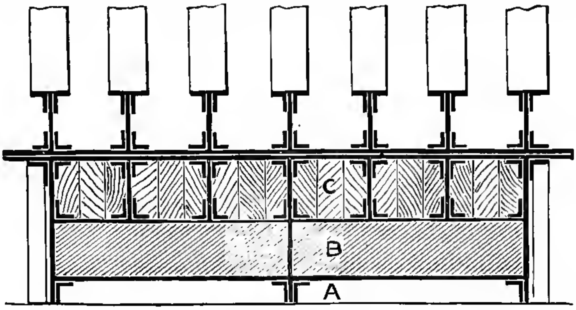
At Shoeburyness, in 1878, one Grüson shot broke up badly, but another did remarkably well (*vide* p. 74, Chap. VI.). The Finspong metal is, of course, remarkably excellent; but no observation is made in this report as to its price. The chilling of the body, still kept up by Grüson, had been abandoned long ago by most manufacturers. In the abstract, the unchilled metal having the advantage in tenacity and the chilled metal in hardness, it would seem sound to retain a little unchilled in the centre, to hold the shot together, while the entire ring of chilled metal might prevent setting up. Practically it has been found better to leave the entire body mottled. The crushing strain there must fall much less heavily than in front, and tenacity throughout the body seems the desideratum.

DETAILS OF THE 17 ROUNDS FIRED ON THE 16TH JUNE, 1879, AT SCHEVENINGEN.

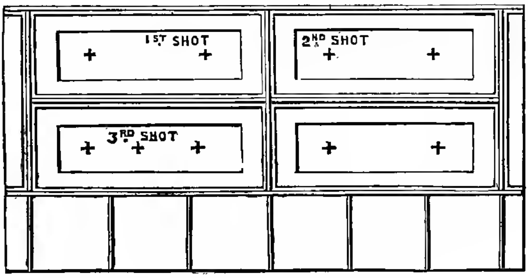
No. of round and maker.	Weight of charge.	Weight of projectile.	Striking velocity.	Stored up work in ton metres per cent. of shot's circumference	Remarks.
	kilogs.	kilogs.	metres.		
1. Ekman ...	16	147·75	266·9	7·116	Struck near top.
2. " ...	"	152·34	266·4	7·311	Do.
3. " ...	"	"	264·7	7·196	Struck junction of plates.
4. " ...	"	"	267·4	7·363	Fairly through.
5. Grüson ..	18	149·65	290·3	8·527	Struck close to 4.
6. " ..	"	"	290·3	8·527	Fairly through.
7. Ekman ...	"	152·34	285·9	8·416	Struck top edge.
8. Grüson ...	"	153·85	287·3	8·584	Fairly through.
9. " ...	"	"	288·7	8·669	Through.
10. " ...	16	"	266·3	7·378	Struck near top.
11. " ...	"	"	262·3	7·159	Just through (*vide* Fig. 1.)
12. " ...	"	"	267·1	7·420	Through.
13. " ...	"	149·65	271·9	7·482	Through weak place.
14. Krupp ...	22·3	161	323·0	11·367	Through thick portion.
15. " ...	"	"	821·5	11·248	Barely through.
16. " ...	"	"	322·6	11·326	Do.
17. " ...	—	—	—	—	Not given.

Spezia Trials, 1879.

In June, 1879, an important trial took place at Spezia against steel armour, with the 100-ton Elswick M. L. gun of 17·72-inch calibre. The general nature of the target may be seen in sectional plan, and in elevation herewith. Steel plates 70^{cm} or 27·6 inches thick, were enclosed in wrought-iron box frames, made of inch iron plate, as shown in Figs. herewith. Each steel plate was about 9 ft. × 4 ft. 7 ins. × 2 ft. 3·6 ins. and weighed 20·8 tons. They were made at Terre Noire and St. Chamond. An iron plate 1 inch thick covered the whole face of the steel. The idea was to hold the steel in its place after fracture, so that a subsequent shot might be resisted by the fragment *in situ.* Steel projectiles were employed made by Whitworth and at Terre Noire, and chilled iron from Grüson and San Vito. The weights varied from about 1918 to 2099 lbs.[1] The Whitworth projectiles were of compressed steel with points inserted like those employed in the Shoeburyness competitive trials. The Terre Noire projectiles had turned bodies but rough heads. The Grüsons had machined bodies and rough heads. The San Vito were chiefly remarkable from their having pieces of india rubber screwed to their upper sides to act as wads. Some projectiles were also furnished by Armstrong & Co. from Elswick, but as they were made for them by Whitworth they need hardly be



SECTIONAL PLAN



FRONT ELEVATION

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[1] One of the highest results in this series had striking velocity 1738 ft., W=2099 lbs. Consequently the striking energy E=43920 foot-tons, e=792·7 foot-tons, and t=29·19 ins. Energy per ton of metal in plate 2111·5 foot-tons.

distinguished. The plates were overmatched. It is difficult to allow for the iron casing on any principle. It is now recognised that a front plate of iron rather facilitates perforation, and one of this thickness at all events, could furnish little resisting power against racking on this scale. Whether judged on the perforation or racking standard, the shot outmatched the plate. The form in which destruction was effected was interesting however. The first round, a San Vito chilled iron shot. The shield kept it out but was much broken and distorted. The general appearance of shot and plate are shown in Figs. 2 and 3.

Fig. 2

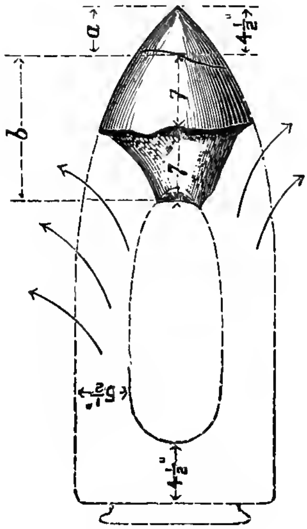


Fig. 3

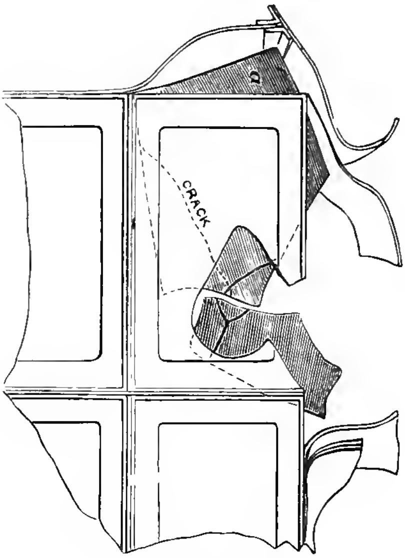


Fig. 4

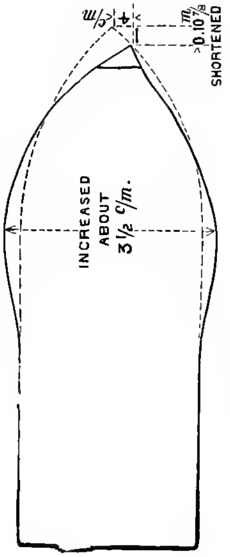


Fig. 5

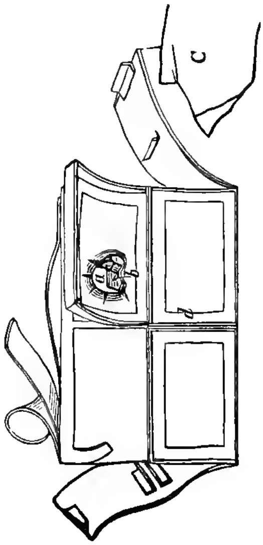


Fig. 6

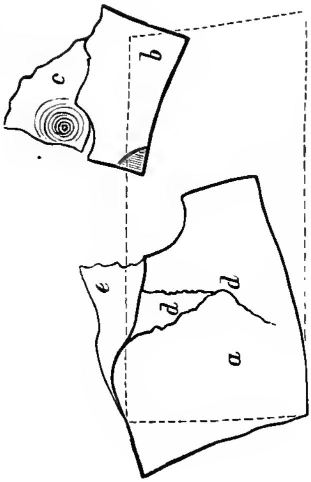
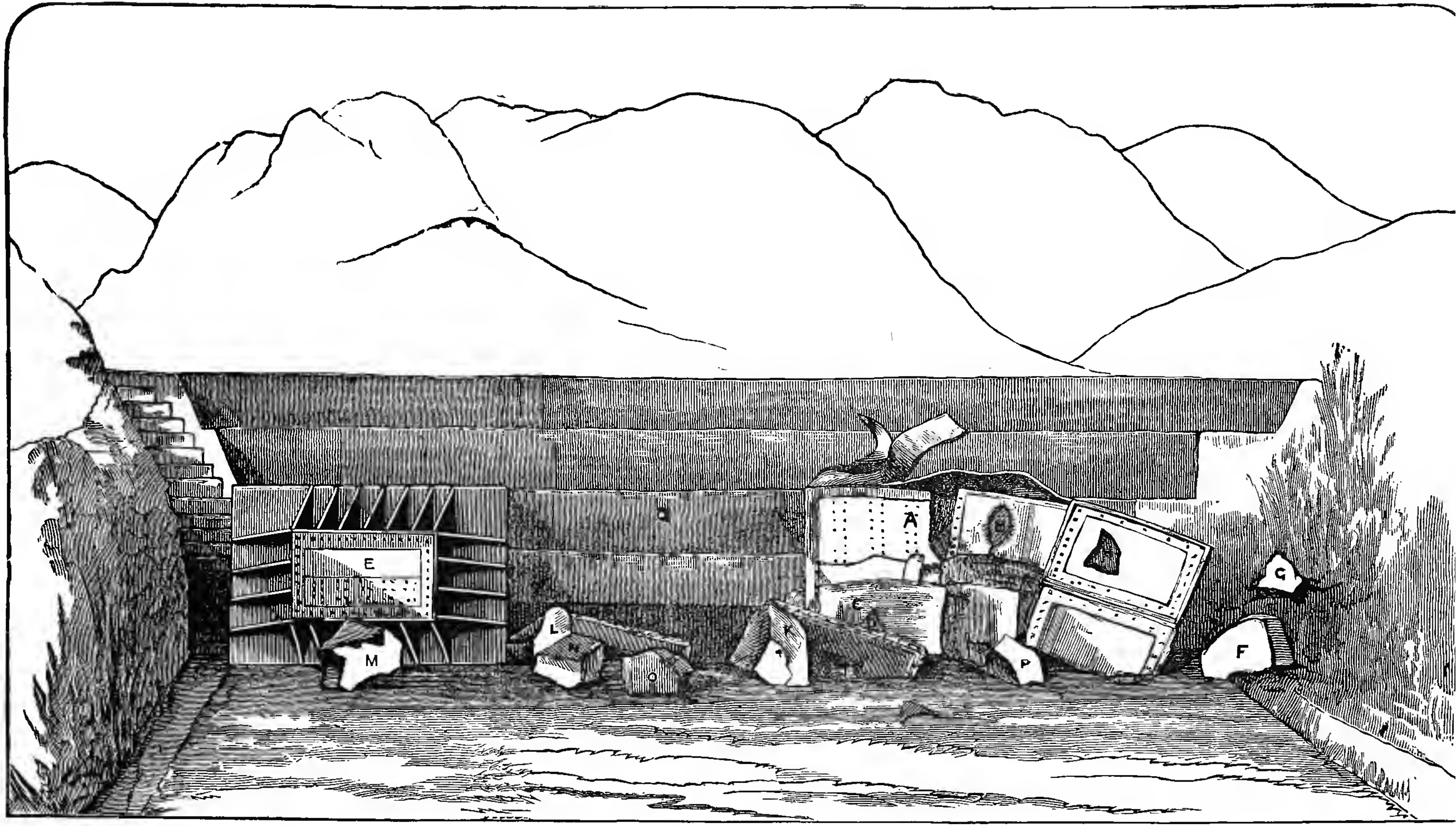
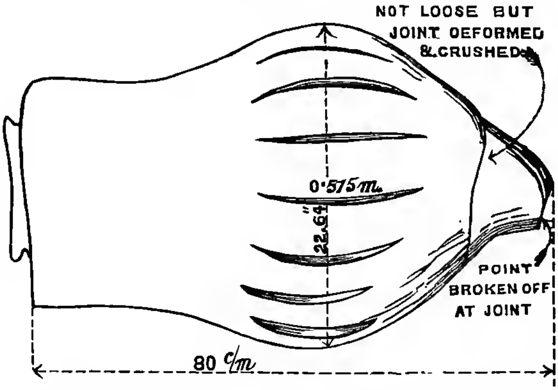


Fig. 1



Round 2 was a Whitworth steel which shattered the shield and actually forced its way through, and was found entire (Fig. 4), the right hand top portion of target being wrecked, the front iron casing being of course perforated and thrown forward, *vide* Fig. 5. Round 3, Armstrong steel shot, supplied to that firm by Whitworth, struck the lower portion in place marked 3rd shot in Fig. showing front elevation, and wrecked the whole structure, *see* Fig. 1. The projectile did not pass completely through and was more set up than No. 2, *vide* Fig. 6.

Fig. 6


NOT LOOSE BUT JOINT DEFORMED & CRUSHED
0·575m.
22.64"
POINT BROKEN OFF AT JOINT
80 c/m

In short, the shot met with a more rigid or harder part, and more was done in racking, and less in perforation than in the case of No. 2. As a whole the experiment was disappointing. It showed the great difficulty of holding steel shields together under blows of sufficient energy to fracture them. In fact, an iron front plate assists the shot to penetrate (*vide* p. 82) while the iron box frames, must clearly be very massive to furnish efficient lateral support.[1]

Krupp's Meppen Trials, 1879.

In August, 1879, Krupp carried out a notable series of experiments at Meppen. The features to be here dealt with are only those connected with armour.[2] [3] Two experiments were directed against armour plates, and two concerned armoured structures. In order of time the two latter came first and were as follows:—

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[1] The support afforded by box frames can only be superior to that given by adjacent steel plates in the grip of the T frames, fastened round the edge of the plate, and holding over the front edge, *vide* A in sectional plan, and C, combined with the hold of the iron covering plate. Without the latter the support would be greatly decreased.

[2] *Vide* Author's Report in "Engineer," August 15, 1879. The author was greatly indebted to Herr Krupp, not only for the enjoyment of the princely hospitality displayed to all guests, in the provision of board, lodgings, special trains, &c., but for what was even of more importance, namely, the most ample means of examining everything, together with the supply of records, photographs, and the use of telegraph wires.

[3] In these trials were exhibited for the first time *publicly* the greatly increased powers of new type guns, and the high standard of accuracy of fire that Krupp had undoubtedly acheived, partly owing to the goodness of German prismatic powder. There were also several new and striking designs. Thus, Krupp's steel breech-loaders were exhibited under peculiarly favourable circumstances, and an impression was produced throughout Europe. There can be little doubt that the adoption of breech-loading guns, and of steel in England, was hastened by these experiments, although in neither respect was Krupp's system followed. All this however should not cause the fact to be overlooked that Colonel Inglis' Sub-Committee had for some time been trying Elswick guns, embodying the features that constituted the so-called new type guns, features that had been arrived at in England, by researches in which Captain Andrew Noble specially took a leading part (*vide* also Abel and Noble's experiments).

On August 5th, 1879, was fired an 11-inch (28^{cm}) rifled howitzer at 28° 36′ elevation, at a canvas structure made to represent the deck of the *Inflexible*, head up the range, length 328 ft. (100 metres) breadth 82 feet (25 metres). The actual length and breadth of the *Inflexible* are respectively 320 and 75 feet. The range was 7327 yds. The shell weighed 476·1 lbs. (216^{kg}). The firing charge was 39·7 lb. (18^{kg}). The vessel was struck as shown in diagram 2, herewith, that is to say, 5 shells pitched on the spot representing the deck of the ship, the four last fired falling very near the centre of it. The importance of this experiment is dwelt on hereafter.

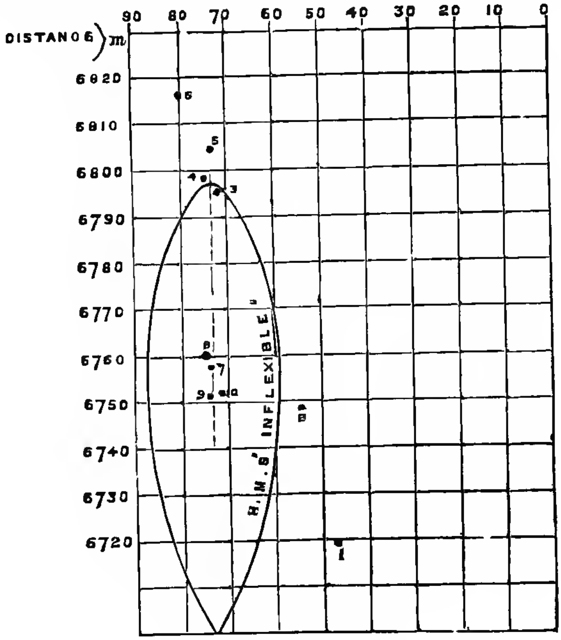

DIAGRAM. 2.

On August 6th, 1879,[1] was fired a 6·1-inch ($15{\cdot}5^{cm}$) gun, weight, 64·9 cwt., muzzle pivoting by ball on muzzle in socket in iron shield, (*vide* Fig. 6, p. 95). The shock of discharge was transmitted through the ball and socket into the shield. However certainly this may entail the gradual destruction of the structure; with this particular gun the process is so very slow that the gun ought to have done a great deal of work before it becomes unserviceable. The speed and accuracy of fire are remarkable. The No. 1 sits on a saddle on the chase of the gun, and lays and fires from that position as fast as the piece is loaded. Owing to the piece having no recoil, it is only necessary to correct the laying of the piece, or leave it laid as in the previous round. The rate of firing was about 1 round in 25 seconds. The projectile weighed 77 lbs., the charge was 14·3 lbs. The plates receiving the shock at the salient where they meet, the tendency is to press them together, and there is little or no perceptible spring on firing. Both muzzle of gun and disc of plate containing the socket are removable. A shield can be run up, covering the salient, at any

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[1] *Vide* "Engineer," August 15th, 1879, p. 122, also Author's paper for U. S. Institution, entitled "Lessons to be learned from the Meppen Trials, 1880," *vide* "Engineer," November 5th and 19th, 1880. This design does not seem to have been adopted, but in certain positions it appears as if it might be most valuable, for example, in the salients or *forts d'arret* of important fortresses, where it would only be exposed to the fire of medium guns, when its speed, safety, and accuracy of fire would make it specially valuable.

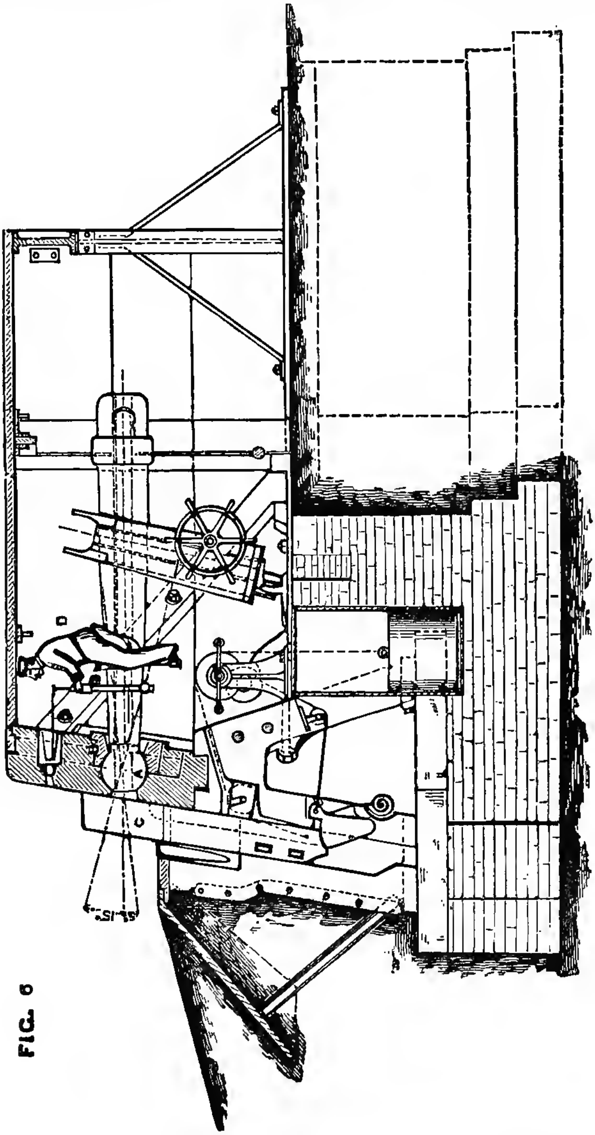
FIG. 6

time, which renders the operation of changing muzzle ball and socket of shield a safe one on service, and also an easy one, unless it should happen that the whole structure is deformed by a crushing blow.

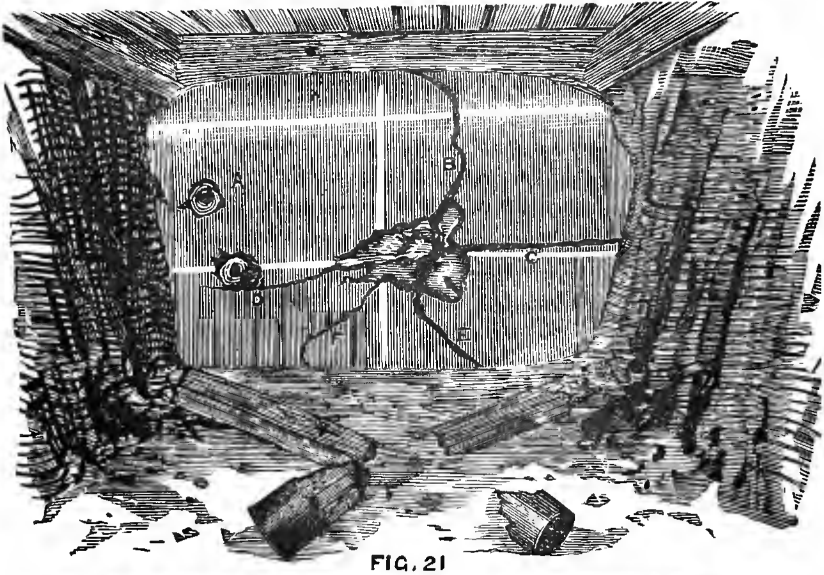

FIG. 21

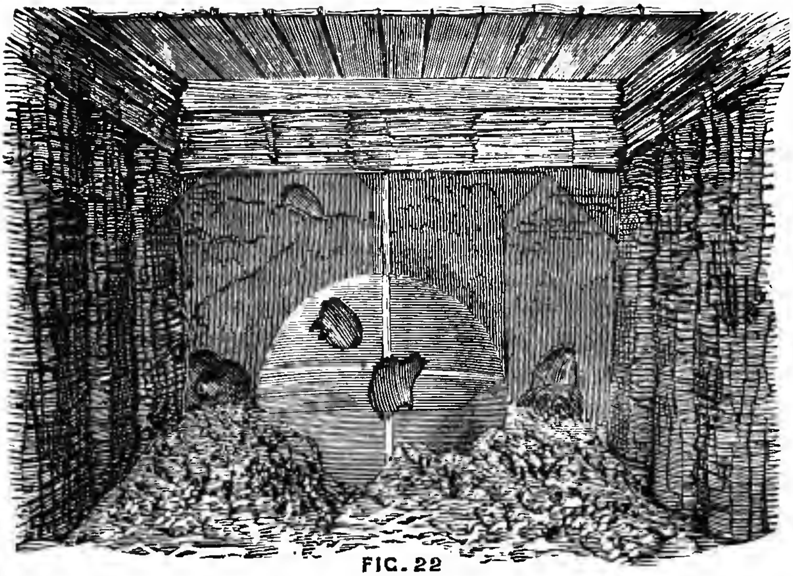

FIG. 22

On August 7th, 1879, Krupp fired at two shields,[1] shown in Figs. 21 and 22, herewith, made to illustrate the behaviour, under fire, of a chilled iron shield ot Grüson's, and one of wrought-iron designed by Krupp. Three rounds of chilled iron shell were fired at each, and four of steel shell from a 6·1-inch ($15·5^{cm}$) gun, with the results shown in Figs. 21 and 22. Under the impact of chilled shell, the chilled iron shield suffered little, but the fire, continued with steel projectiles, cracked it through. Grüson naturally repudiated all responsibility for the behaviour of a chilled iron shield which Krupp designed and made, with a view of showing its inferiority, but on the whole the shield behaved well, better probably than Krupp expected. The chief lessons to be learned from the experiment was, the unsuitability of chilled shot for the attack of chilled iron, in other words; the power of chilled iron to resist[1] chilled shot, but its liability to fracture when steel ones were employed. Finally, two rounds were fired from a 9·45-inch gun[2] (24^{cm}) at a shield made of wrought-iron plates from Dillingen, ***vide*** Figs. 23 and 24, herewith. There was a front iron plate 12 inches thick, $30·5^{cm}$, then a thin layer of wood nearly 2 inches thick ($5·0^{cm}$), and behind it an iron plate 8 inches ($20·5^{cm}$) thick, for area (*vide* Fig. 23). The projectile was steel, it weighed about 348 lbs. (158^{kg}) the firing charge was 165·3 lbs. (75^{kg}), the striking velocities were 1877 feet (572 metres) and 1852 feet (564·5 metres). This gives, in the case of

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[1] *Vide* "Engineer," August 15th, 1879, p. 123.

FIG. 23

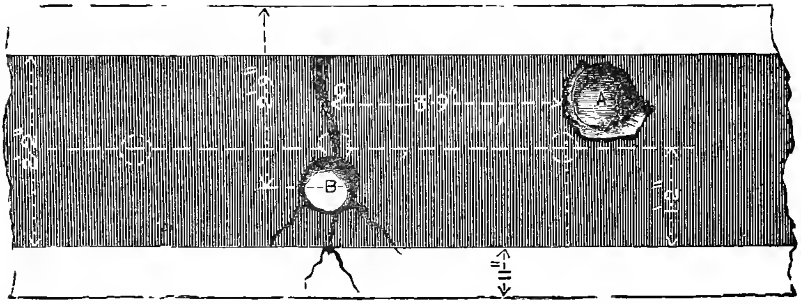
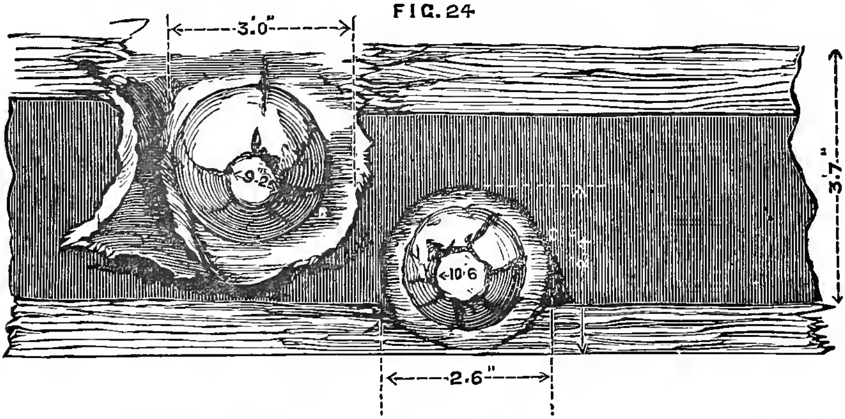


FIG. 24



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[1] Krupp hardly showed his usual amount of shrewdness in this trial. The 6·1-inch gun was a punching gun, with high power of perforation in proportion to its energy, and therefore suited to cut deep into wrought-iron, as it did, rather than shatter the chilled shield. To English Officers, hardly any of whom have seen chilled iron shields under fire, the experiment was very instructive.

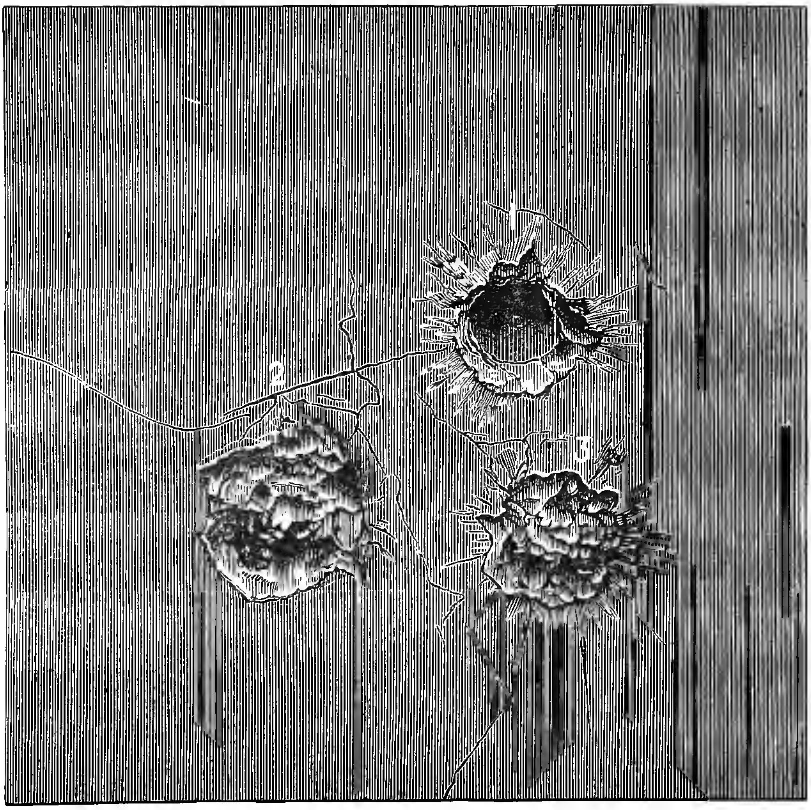
[2] *Vide* "Engineer," August 15th, 1879, p. 123.

the second round, a striking energy $E=8287$ foot-tons, energy per inch circumference $e=279\cdot2$ foot-tons, $t=17\cdot52$ ins., in a single plate, and in two thicknesses $t=18\cdot3$ ins. As may be seen in the Figures the projectile passed easily through the entire shield in both rounds, and passed up the range over 3000 yards. These two projectiles were as little deformed and injured by the work they had done as those of Whitworth, under similar circumstances. To Officers who had not witnessed an exhibition of the powers of new type guns, and had not seen the behaviour of excellent forged steel projectiles, it almost looked like a conjuring trick to see projectiles cleave their way clean through more than double their diameter and passed on up the range uninjured, to the eye, almost as if they had been through a wooden target. Those who had had to deal with guns and projectiles of the most recent kind would scarcely expect the shot to perforate the target as shown by the figures above, and some explanation must be sought for a projectile whose perforation works out 18·3 inches in 2 plates, passing easily through 20, and continuing its flight without grazing for some hundred yards. The problem may be divided into the effect that is due to the gun, supposing the projectile to be of an average kind, and that is due to special peculiarity in shot or plate. The perforation due to the gun's powers is a simple question of energy in proportion to the bore, and, with the data established by past experience, may be found by taking the velocity without firing at a plate at all. The actual effect on a plate tests the qualities of projectile and plate. So far as the type and powers of gun and powder go, the result is 18·3 inches through iron arranged in 2 plates. The extra effect must be traced to excellence in shot or badness in plate. The latter undoubtedly may be seen to have behaved rather badly. The effect, though not well rendered in the cut, is obviously that of shot or badly welded plates. Some fault has been found with the bolting and with the thinness of the layer of wood between the two plates. As already pointed out (p. 9, Chap. I), plates may crack across from the insufficiency of wood between them as these plates did, but in the actual case of perforation, another cause, namely the bad welding, is more likely concerned, but does not seem sufficient to go nearly far enough to account for the great excess of perforating power in question. The projectiles were of most excellent steel undoubtedly, and the points were very sharp, being ogival struck with a radius of 2 diameters. The data for English's system of calculation have been furnished with points of 1½ diameters radius, and this no doubt enters into the question. It may not at first appear necessary to analyze an isolated experiment on perforation as has been done. It is however very important to gauge foreign results, especially those obtained by Krupp, in all possible ways. The powder due to the gun which is registered by the velocity is a matter easily dealt with. The relative powers of any gun of our own and one made in Germany are patent, if the velocity is known. Any power due to special excellence in the projectile is much more likely to escape observation, and in the branch of development it is easy to drop behind without perceiving it. (This question is dealt with again hereafter). Those special qualities of a shot are of course more important which apply both to punching and racking; thus, effect due to tenacity is probably more important than that due to shape of head.

Nettle Steel-faced Plate Trials.

In June, July and August, 1879, a steel-faced 9-inch plate for H. M. S. *Inflexible*, was tried on board the *Nettle*, by a 9-inch 12-ton gun in the usual way, but greater penetration than usual was obtained by the chilled shot, which of course broke up. Some details are given in the Director of Artillery's Departmental records, but it is difficult to judge of the effect without sketches or photographs.[1]

On April 20th,[2] 1880, an experiment took place with a 9-inch Cammell-Wilson steel-faced plate, in the course of proof of plates, on board the *Nettle*, at Portsmouth, which may serve to show the progress made. The service 9-inch gun fired a 257 lb. Palliser projectile with a striking velocity of about 1460 feet per second, giving a total energy $E=3799$ foot-tons, an energy per inch $e=135\cdot6$, and perforation $t=12$ inches, the energy portion of plate was 1039 foot-tons, supposing the plate to weigh 5 tons. The plate had a steel-face of 3½ inches thick, and a wrought-iron foundation plate 5½ inches thick. The area of it was 6 ft. × 5 ft. 8 ins., it was bent into the arc of a circle of 16 ft. 11 ins. radius, measuring to the steel face. The cuts, herewith and p. 100,



FRONT OF PLATE

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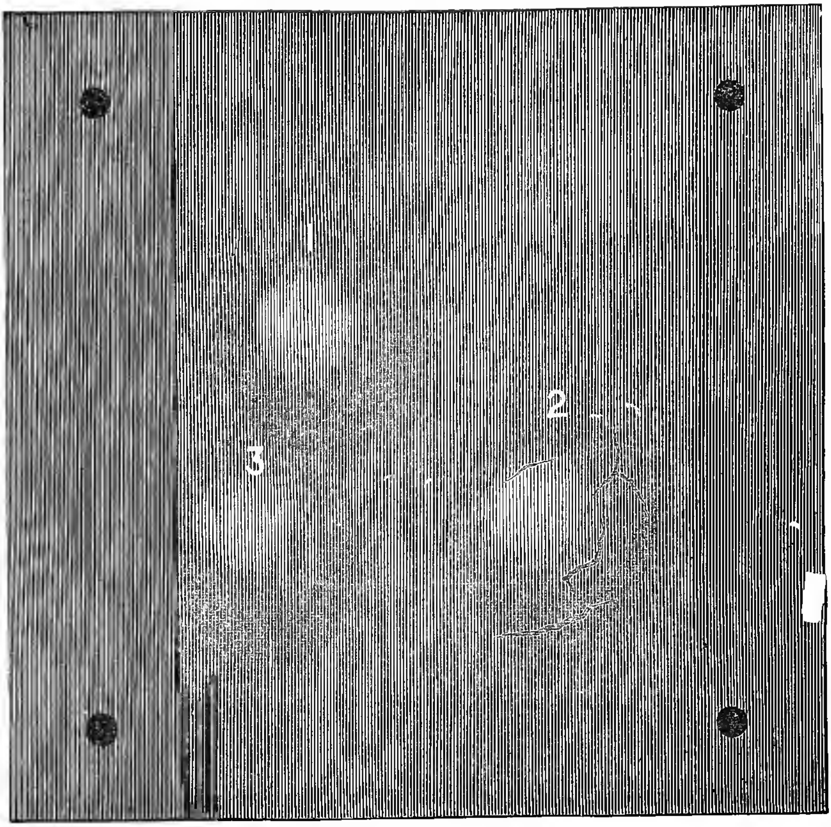
[1] *Vide* D. of A. "Proceedings," 1879, Vol. XVII., pp. 151, 224.

[2] *Vide* "Engineer," June 11th, 1880, p. 417.



BACK OF PLATE

show the effect produced by 3 rounds, the depth of indent of the first shot which was dislodged by those subsequently fired was 5·8 ins. The plate in this case stood admirably, having borne 3 rounds, each of which would have perforated an iron plate of 12 inches thickness, and still being in a condition to offer considerable resistance to further firing.

On July 21st, 1880,[1] an 18-inch steel-faced Cammell-Wilson plate was fired at by the 38-ton gun at Shoeburyness, area of plate $9\frac{1}{2} \times 8$ ft., projectile, Palliser chilled, weight 828 lbs., firing charge 180 lbs. P^2 powder, range 227 ft., striking velocity 1504 ft., striking energy $E = 12980$ foot-tons, energy per inch circumference, $e = 322{\cdot}5$, perforation $t = 18{\cdot}7$ ins., weight of plate about 24 tons, energy per ton of plate 541 foot-tons. The effect on the plate is shown in elevation and vertical section, p. 101. It will be seen that the shot broke up badly against the steel face, a circle of deep indentations 1, 2, 3, 4, 5, 6, 7, and 8 being made on the plate round the point of impact, two rather deep horizontal cracks may be seen in elevation herewith. Obviously the shot was prevented from delivering its energy well at the point of impact by being broken up abruptly by the hard surface of the shell. This is an example of loss of effect from want of tenacity in chilled iron shot.

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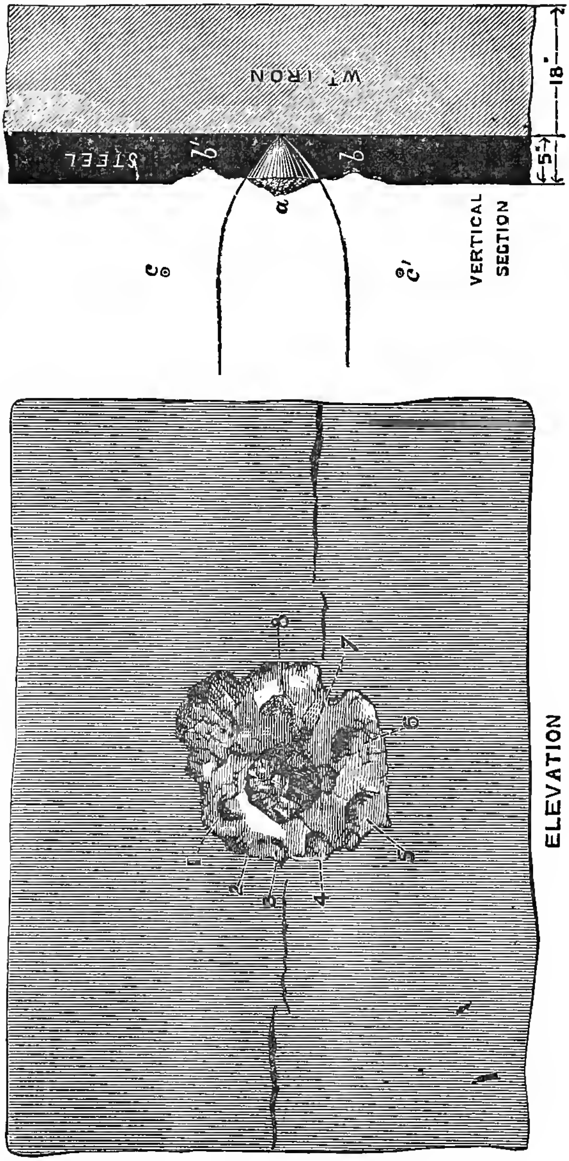
[1] *Vide* "Engineer," July 30th, 1880, p. 79.



Krupp's Meppen Trials, 1882.

On March 29th and 30th,[1] 1882, Krupp, during the course of gunnery experiments at Meppen fired long 5·9-inch (15^{cm}) gun at a target consisting of two[2] 6·9-inch wrought-iron plates, with 9·8 inches of

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[1] "Engineer," October 6th, 1882, p. 251.

[2] More exactly $17{\cdot}5^{cm}$ (6·89 ins.) wood 25^{cm} (9·84) ins. D. of A. "Proceedings." Vol. XX., p. 380.

p. 380.
p. 380.
p. 380.
p. 380.
p. 380.

wood, (*vide* Fig. 2, herewith), at 164 yards (150^{m}) from the muzzle. The projectile was a steel shell weighing 109·6 lbs. ($49{\cdot}7^{kg}$). The charge in the second round, which being the weaker, is the one to consider, was 37·5 lbs. (17^{kg}). The striking velocity was 1750 feet ($533{\cdot}5^{m}$). The striking energy $E = 2328$ foot-tons, $e = 126{\cdot}3$ foot-tons, the thickness that might be perforated $t = 11{\cdot}7$ ins., this projectile, as well as the first fired, passed easily through the entire target, and went on up the range, this one to a distance of 328 yards, where it was picked up uninjured, (*vide* Figs. 2, 3, 4 and 5, pp. 102 and 103). As in the plate firing in 1879, the perforation was more easily performed than can be

HORIZONTAL SECTION
FIG. 2

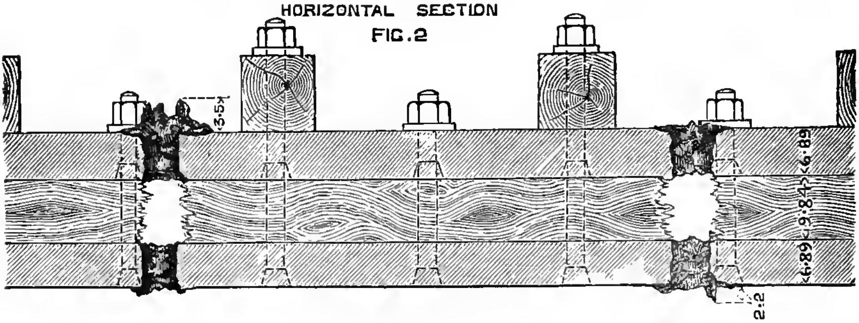
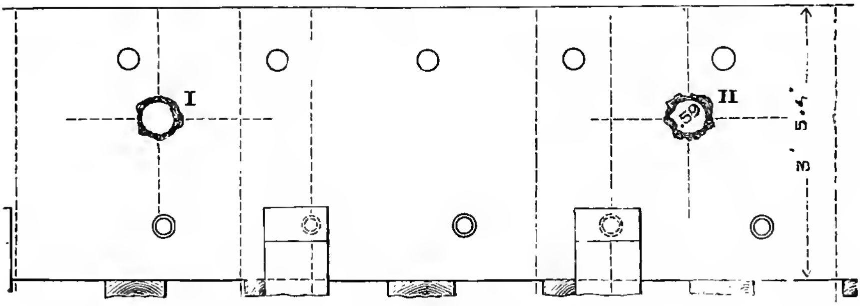


FIG. 3 FRONT VIEW



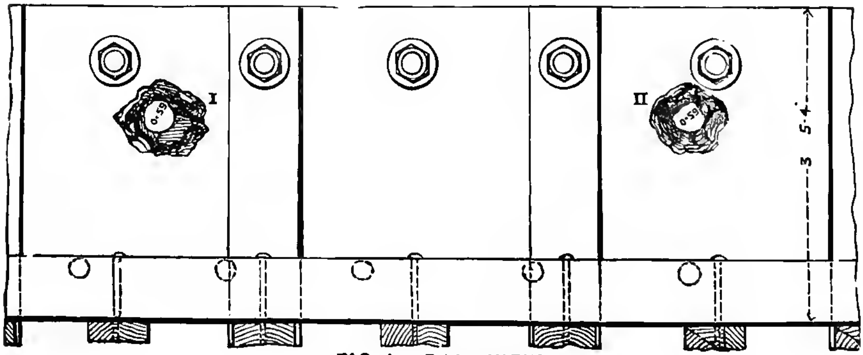
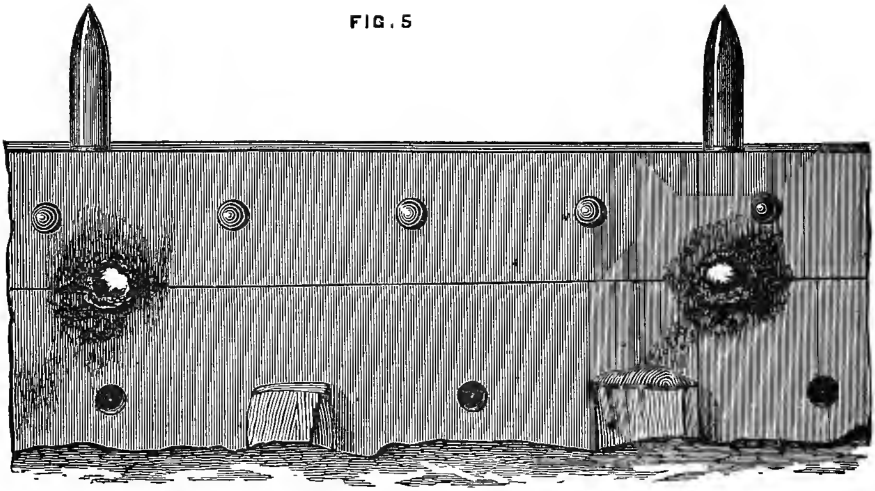


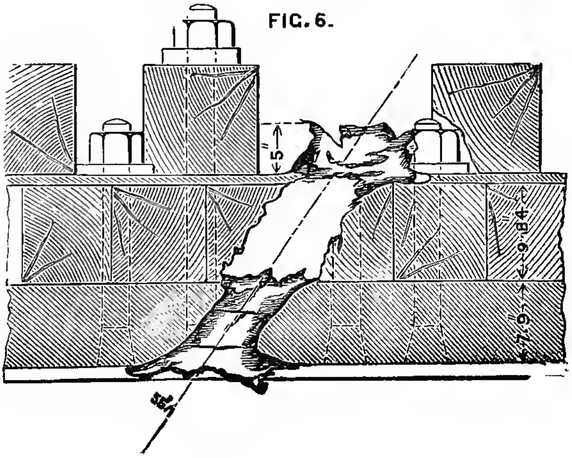
FIG. 4 BACK VIEW

FIG. 5



accounted for by calculation of the power of the normal English shot from this gun with the given velocity, and this must be attributed to excellence in shot, badness in target, or to both combined. The material of the plates was exactly that of our own, being Sheffield plate supplied to the German Navy. The wood between them, however, was in this case much too thick, judging from the Shoebury trials (see p. 9, Chap. I.). It may seem unfair to object to the wood employed in 1879 as too thin and that of 1882 as too thick, but having definitely arrived at the conclusion that about 5 inches is the proper thickness for a layer of wood, and having given definite mechanical reasons for it, it is not captious to object to 10 inches as too thick, 2 inches as too thin. Nevertheless it is probable that the excellence of the shot and the sharpness of the point contributed to the good result. Two rounds from the same gun were also fired at an angle of 55° (35° with the normal) at a wrought-iron plate 7·9 ins. (20^{cm}) thick, charges of 39·7 and 37·5 lbs. (18 and 17^{kg}) were employed. Even with the latter complete perforation was effected (*vide* Figs. 6 and

FIG. 6.



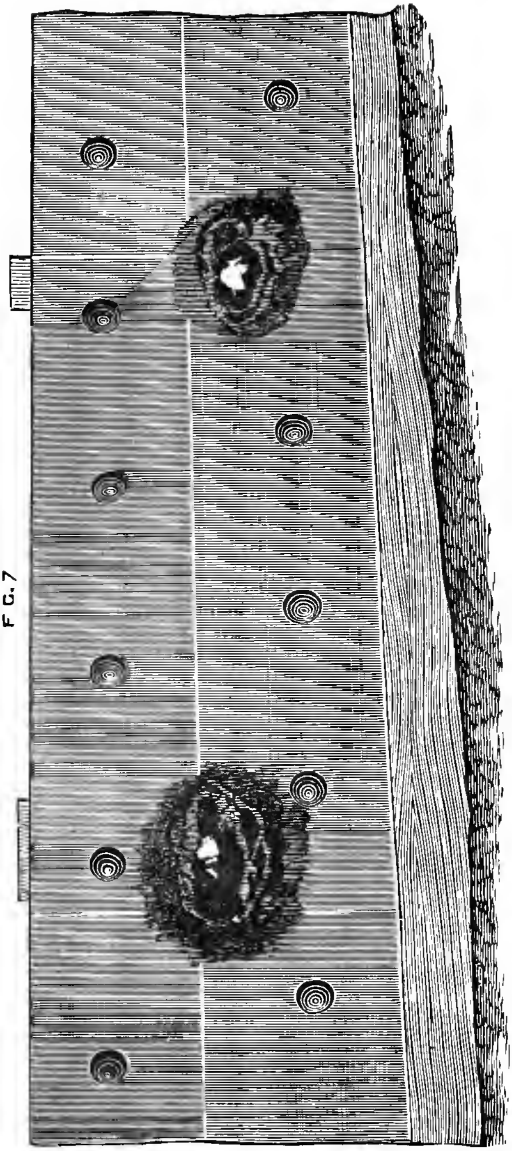


FIG. 7

7, pp. 103 and 104), the projectiles however were both broken up, as commonly happens in oblique penetration. With the smaller charge the striking velocity as in the direct firing, was 1750 ft., with which, the striking energy $E=2328$, energy per inch $e=126{\cdot}3$ foot-tons, thickness that might be perforated $t=11{\cdot}65$. This multiplied by the sin 55° gives 9·5 ins., as the thickness that might be perforated at this angle of incidence. The shell therefore was more than a match for the plate. The angle of incidence is that which Col. Inglis'

Committee found to be about the limit at which a projectile would bite even when more than a match with the plate. There were no further plate experiments at Meppen at this time, it may, therefore be seen that Krupp confined his experiments to the perforation of soft armour.

Palliser improved Projectiles.

On June 6th, 1882,[1] some special projectiles designed by the *late* Sir W. Palliser to act against steel-faced plates, were tried at Shoeburyness under the direction of Captain Palliser, brother to the *late* Sir William. This form of Palliser shot has a steel jacket or jackets shrunk on to its body to hold it together at the instant of impact, (see Figs. 1, 2 and 3, herewith). It has ribs on its head running longitudinally, see Figs. 1, 3, 4 and A, with a view to split the armour. Lastly, its jacket being left behind in penetration, the diameter of the shot is reduced, and in perforation meets with a proportionally decreased resistance. It may be seen that the body is slightly tapered

FIG.2.

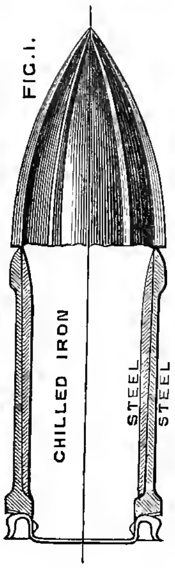


FIG.1.

RIBBED & JACKETED PALLISER SHOT WITH FIXED UNDER JACKET & MOVEABLE UPPER JACKET

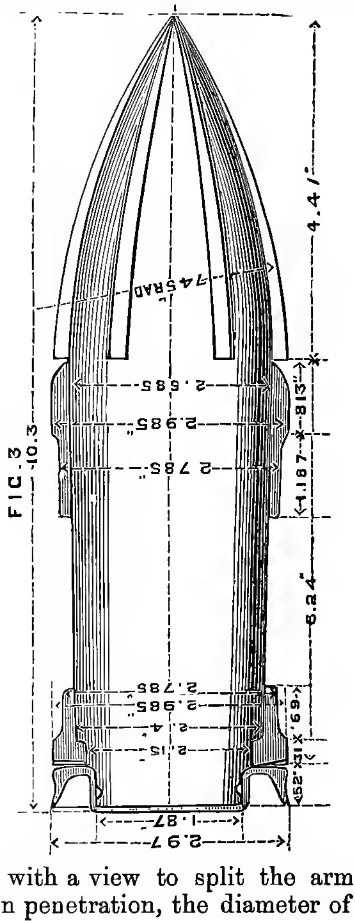


FIG. 3

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[1] See " Engineer, June 9th, 1882, pp. 411 and 421.

to facilitate escape from the grip of the jacket. The shot in Fig. 1, has its body enclosed in a second jacket, which remains on it. It may be seen that in this design perforation is contemplated for in the case

FIG.4

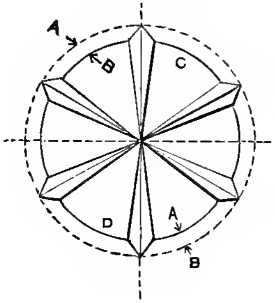
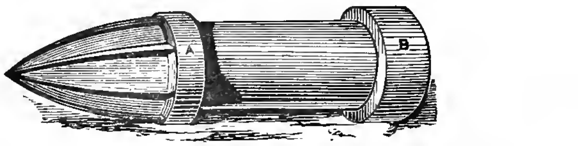
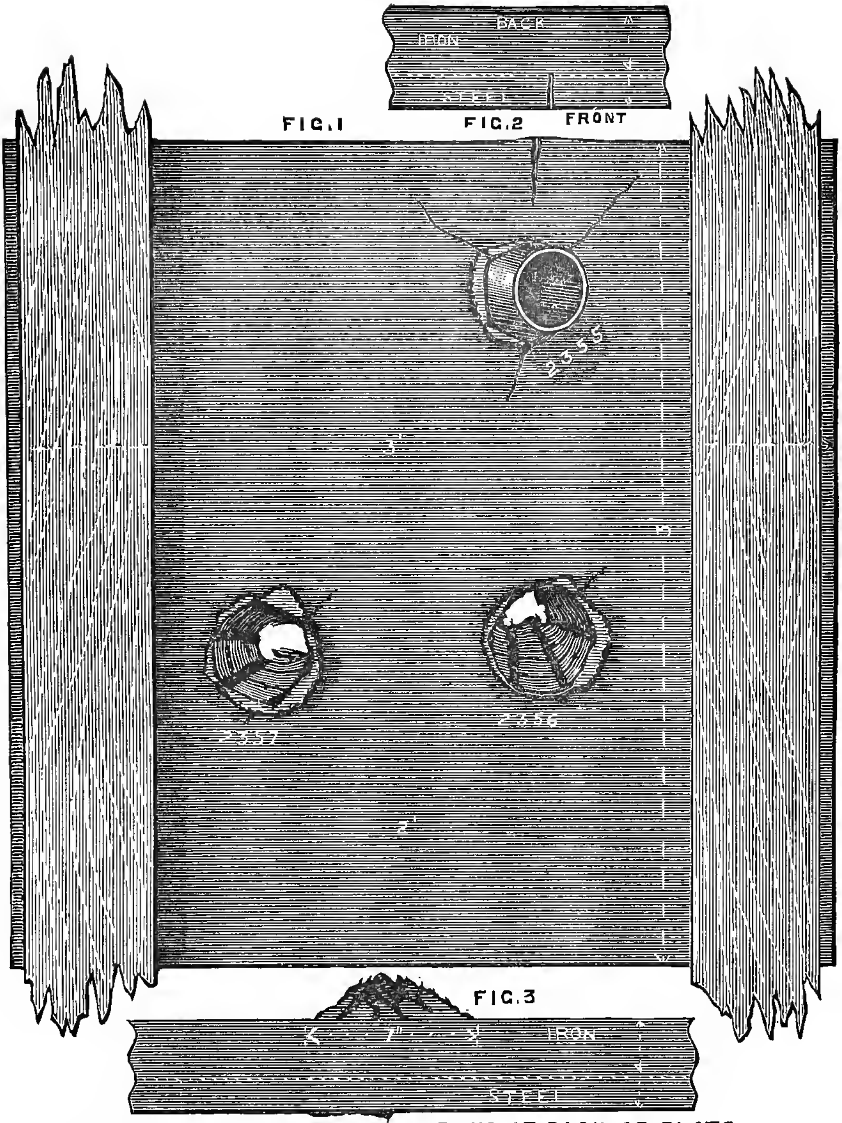


FIG A



of a plate which cannot be perforated by any means, the reduced diameter is of no advantage. On the occasion referred to, a 13-pr. gun (3-inch bore) the shot weighed about 13 lbs., the charge was $3\frac{1}{4}$ lbs., the velocity was about 1550 feet, the striking energy $E=$ 216·5 foot-tons, the energy per inch circumference $e=26{\cdot}7$ foot-tons, and the thickness of iron that might be perforated $t=4{\cdot}9$ inches, with a service projectile of 2·985 in. diameter, with Palliser's reduced diameter of 2·585, it would be 5·3 inches. The plate against which the shot were fired was a Cammell-Wilson steel-faced plate 4 inches thick. According to the conclusions of Colonel Inglis' Sub-Committee this is equal to 5·05 inches wrought-iron, consequently, supposing the Palliser projectile to escape from its steel jacket without loss of energy, and supposing the plate to yield by perforation rather than fracture, the Palliser improved shot ought just to get through. It will be seen in Figs. 1 and 3, p. 107, that three projectiles fired passed completely through the plate with some energy to spare, indenting an old plate in rear. The shot themselves broke up. In the first round, No. 2355, the projectile had a double steel jacket, and left its outer jacket behind it as shown in Fig. 1, very neatly. It was impossible to say whether the body of the shot remained entire before striking the old target in rear or not. The second shot (round 2356) had a single jacket, and the third (No. 2357) a short steel ring. A wooden gun carriage bracket was placed behind the plate to prevent the shot if possible from fracturing themselves, or, should they be fractured by the compound plate, catch the broken pieces. It appeared that No. 2 was fractured, and No. 3 was broken into smaller pieces. A service chilled projectile, fired afterwards at the same target, broke up without perforating the plate, making a moderate bulge in the back. This trial was singularly successful, therefore, and was naturally followed up by further experiments by Capt. Palliser. The ribs appeared by the marks in the perforations to have done well. The steel jacket seemed to act more effectually as it increased in size. There appears, however, to be a limited scope for the gain effected by decrease of diameter, as its value



HORIZANTAL PROJECTION SHOWING OPENING AT BACK OF PLATE

depends on the power of forcing the plate to yield by perforation ; this cannot apparently be achieved with the hardest classes of armour, namely, solid steel and chilled iron. The increase of tenacity afforded by the steel jacket applies to all forms of destruction of armour. Fig. 4 shows the first form of projectile tried on this system by Sir W. Palliser, namely, a chilled iron Minié bullet, with steel ring.

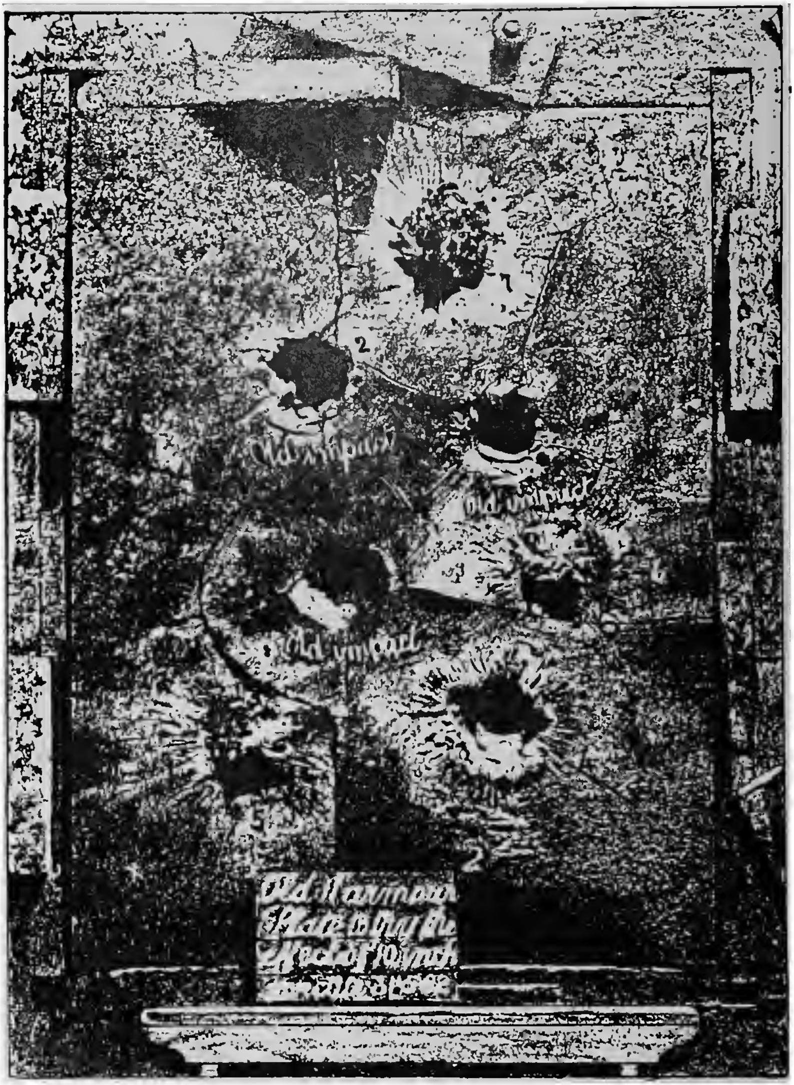
(The attack of Alexandria by the British Fleet is discussed hereafter).

Cammell and Brown's Plates, 1882.

The progress in the manufacture of compound (steel-faced) plates may be illustrated by the trials made against plates by the two great Sheffield firms which had taken up this work, namely Cammell's and Brown's. The former[1] took place on board the *Nettle,* in the course of proof of armour plates, the latter in experimental firing at Shoeburyness.

The Admiralty conditions of test were the following:—"A test

Fig. 1



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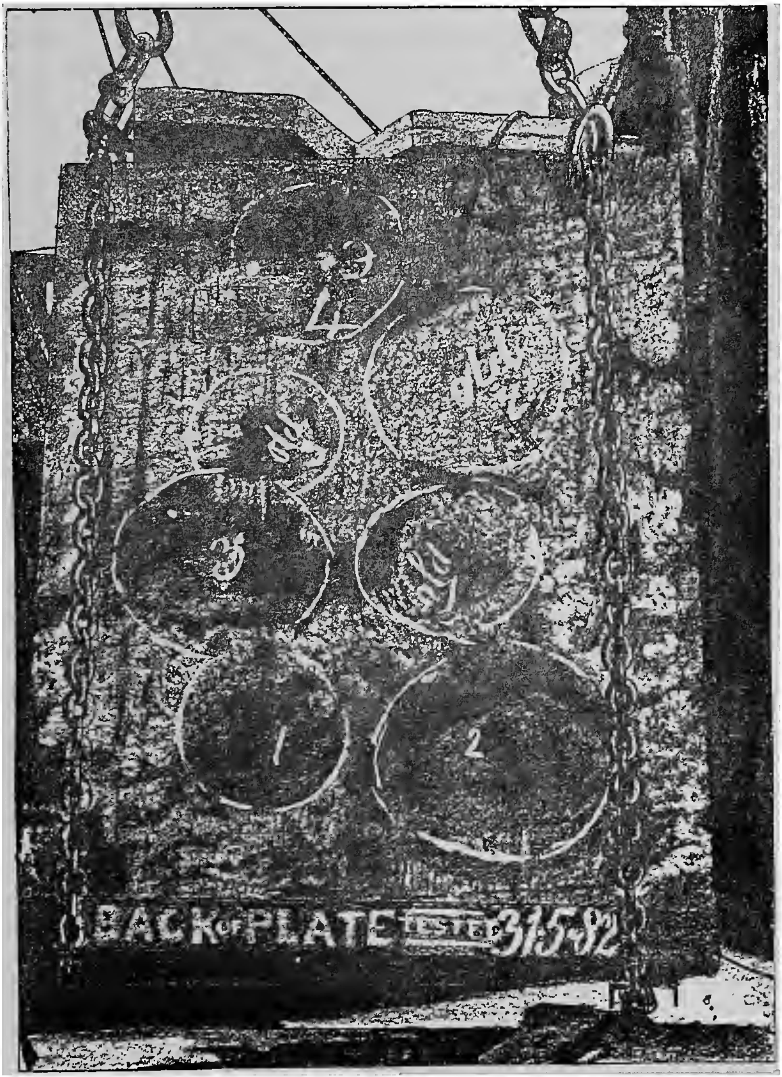
[1] *Vide* 'Engineer,' August 11th, 1882, p. 97.

piece, not less than 8 feet × 6 feet, nor less than 9 ins. in thickness, shall receive a 9-inch chilled cast-iron projectile fired from the service 12-ton gun with 50 lbs. of powder, at a range of ten yards without cracking through, and, provided it be surrounded by a frame, no one of three such projectiles shall be capable of getting through, there being a fair distance between each two shots, say 2 feet, as in the trials of the *Inflexible* turret armour." This test is a very severe one; a projectile thus fired has a velocity of about 1420 feet, and a striking

Fig. 2



JOHN SWAIN SC

energy of about 3608 foot-tons,[1] being about a match for 11½ inches of unbacked wrought-iron. Since Colonel Inglis' Committee considered that a good compound plate, between 9 and 10 inches, was equivalent to a good 12-inch wrought-iron plate for a single blow, but not for repeated blows, the fact that this plate bore all the firing shown in Figs. 1 and 2, pp. 108 and 109, without cracking at the back, shows that the plate was excellent, and also that the shot must have broken up badly. Steel 9-inch projectiles got their heads through 12-inch unbacked plates in the competitive projectile trial at Shoeburyness, some chilled shot got their points through. The resistance of this 9-inch compound plate was therefore remarkable. The following rounds were fired at it:—three rounds with 9-inch projectiles producing only slight bulges at the back; four rounds with 10-inch Palliser projectiles weighing 400 lbs., with 70 lbs. firing charge, at 10 yards distance, striking velocity = 1364 feet,[2] having a striking energy $E = 5160$ foot-tons, and a calculated perforation $t = 13·1$ inches of unbacked iron, or 10·4 of compound plate. After the whole seven rounds the plate was only bulged at the back without cracks, the greatest bulge being about $1\frac{1}{16}$ inches high, while the deepest indent was 4·7 inches. The total work borne by the plate was therefore about 31,464 foot-tons (nearly the blow of the 100-ton M. L. gun shot) and the enormous strain of 3314 foot-tons per ton of metal, supposing the plate to weigh about 9½ tons.

The steel-faced plate of Messrs. Brown, above-mentioned, tested at Shoeburyness, was made on Ellis' patent[3] (*vide* manufacture, hereafter); it measured 10 feet × 5½ feet × 11 ins. thick, made up of about 4 ins. steel or 7 ins. iron. The steel contained about 0·75 per cent. carbon.[4] The plate was backed by about 24 inches of oak, and was first attacked by the 9-inch gun (12-ton), firing Palliser chilled projectiles weighing 260 lbs., the powder charge being 50 lbs. of pebble. Three rounds were fired with striking velocities of 1430, 1444, and 1432 feet, and striking energies, E, equal to 3686, 3760 and 3697 foot-tons respectively, energies per inch (e) of 131·5, 134·2 and 131·9 respectively, and perforation (t) of 11·7, 11·8 and 11·7 respectively. A fourth round was fired with a studless Cammell steel projectile weighing 279 lbs., a striking velocity of 1405 feet, and a striking energy of 3818 foot-tons, energy per inch (e) of 136·2 foot-tons, and perforation $t = 11·88$ inches of iron, equivalent according to Colonel Inglis' Committee to 9·4 of compound plate.

Fig. 1 p. 111, shows the plate at the conclusion of this firing, it had then borne a total amount of energy of 14,961 foot-tons. In October, 1882, the same plate was re-erected, backed by 12 inches of wood, and behind that an old 12-inch compound plate. In the meantime a star-shaped crack had developed in the face near the opposite end to that fired at, showing how much more extensive was the molecular action developed by impact than may appear. Two rounds were then fired from the 38-ton gun (12·5-inch) at a range of 93 yards, with steel projectiles weighing 840 lbs. and 845 lbs., fired with charges of 160 P^2 powder, giving striking velocities of 1425 and 1413 feet respectively, and striking energies of about 11,820 and 11,690 foot-tons, the former having an energy per inch (*e*) of 302·9 foot-tons, and a perforation $t = 19·88$ ins. iron, or 15·4 compound plate. The total energy of all the six blows on the plate then amounted to 38,471 foot-tons, or taking the plate at 11 tons, 3497·4 foot-tons per ton of plate.

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[1] $W = 258$ lbs., $E = 3608$ foot-tons, $e = 128·7$ foot-tons, $t = 11·6$ ins.

[2] $e = 165·6$ foot-tons.

[3] *Vide* Paper by Major O'Callaghan, R. A., in R. A. Institution "Proceedings," May, 1882, Vol. XII, also "Engineer," September 8th, 1882, p. 182.

[4] Both in the face plate and the metal by which it is attached to the iron.

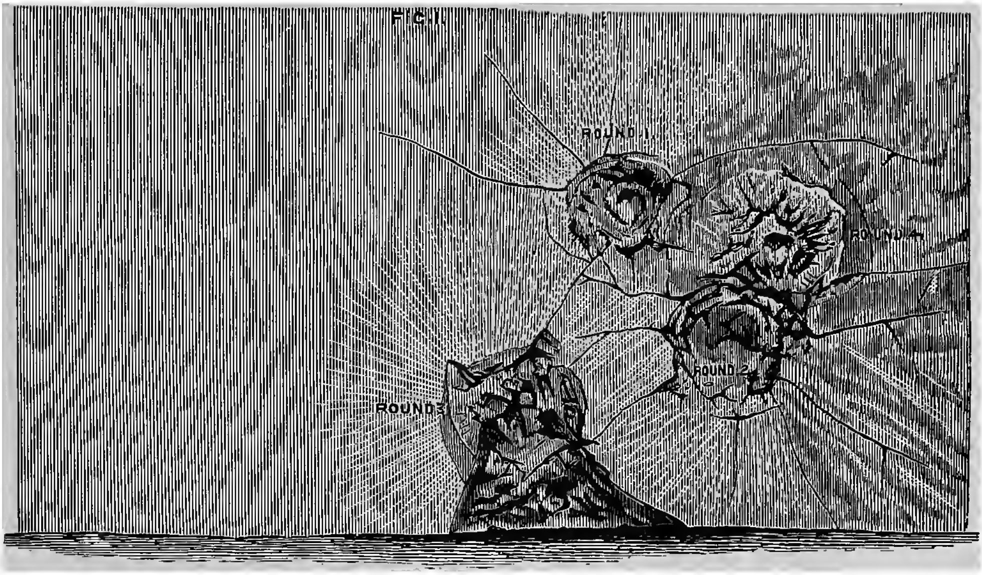


FIG. 1.

This plate may naturally be compared with the Cammell-Wilson plate, whose trial on board the *Nettle* has just been noticed, or a Brown-Ellis plate, which was tested on board the *Nettle* in February and July, 1882, might have been taken in preference to this one. It was an admirable plate, and appeared to behave in the same way as its rival, but as it was tested with only three 9-inch and three 10-inch projectiles, and the Cammell plate with three 9-inch and four 10-inch, the total work delivered on the plates differed considerably. It may be seen that the Brown plate at Shoeburyness suffered much more than the Cammell on the *Nettle*, discs of the plate being driven out by the 12·5 projectiles (*vide* Figs. 3, 4 and 5, pp. 112 and 113), but this is accounted for by the plate being more severely tried by the greater concentration of the energy into individual blows. The Brown-Ellis plate had borne 3497 foot-tons per ton of plate, the Cammell-Wilson 3314 foot-tons. As to racking or shattering strain, the difference in amount then was not such as to tell so heavily as in the manner of application. An 11-inch plate exposed to the blow of a shot with 15·4 calculated perforation is much more severely tried than a 9-inch plate exposed to one with 10·4 perforation; and it will be seen that the Brown-Ellis plate actually yielded locally. Were this however the whole difference in

FIG. 3

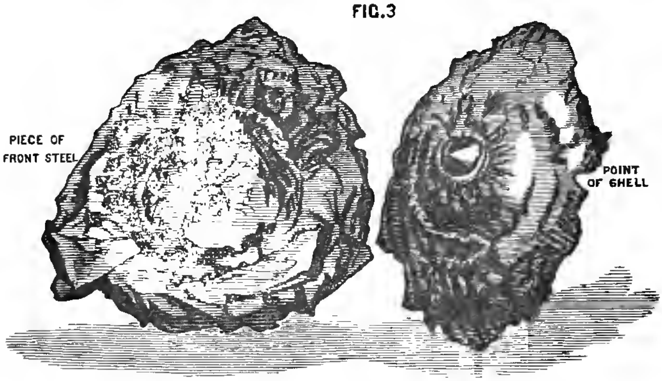
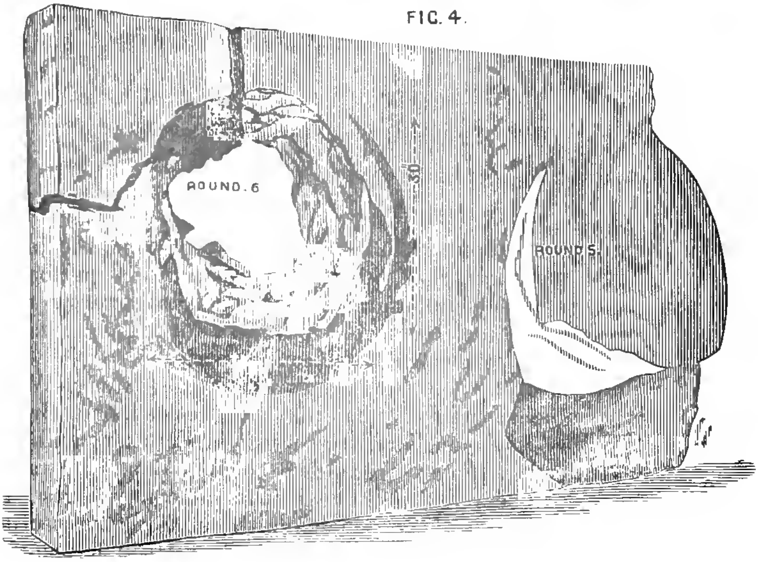


FIG. 4.



the strain to which the plates were subjected, it would probably be felt that the Cammell-Wilson plate had stood the best, there is however the more important fact that the three last projectiles fired at the Brown-Ellis plate were steel. Probably any one comparing the two *Nettle* plates as well as this one at Shoeburyness would fail to see any advantage obtained by one system of compound armour over the other. In fact, the comparison of two results when the conditions are not strictly similar, is more useful in calling attention to peculiar features, than in establishing data to measure the relative powers of the two systems. Leaving the question of comparison to trace further features in the behaviour of the plates it may be well to quote the excellent

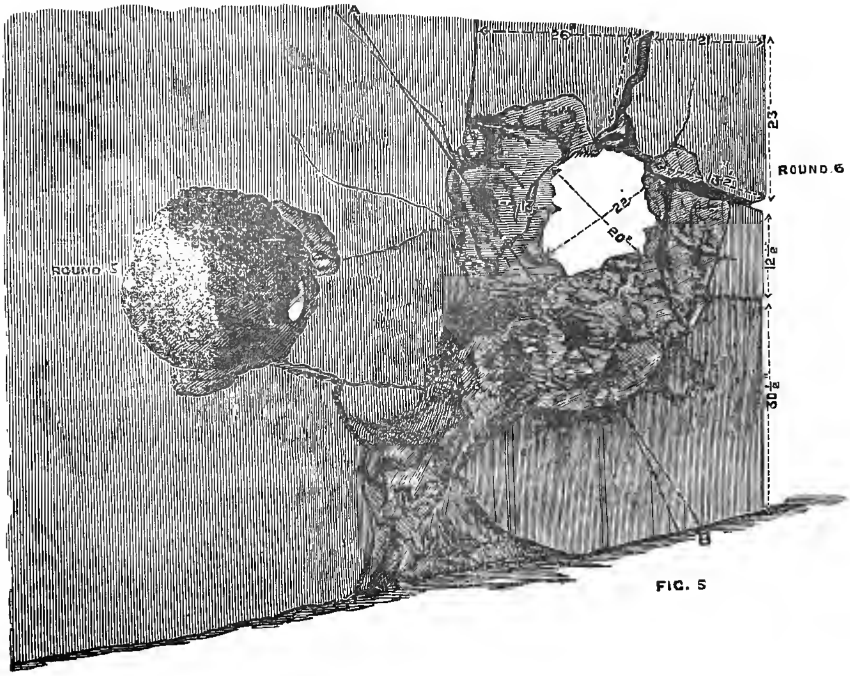


FIG. 5

paper of Major O'Callaghan who conducted experiments under the Commandant at Shoeburyness at this time. He writes, on the Brown-Ellis plate, as follows:—"A large layer of steel was found to have come away from the front in the region of the indents made by the 9-inch projectiles, disclosing a very curious configuration of the steel round these depressions. Fig. 5 shows the crater like form they exhibit, and Fig. 6 is a cross section through A B, showing their depth

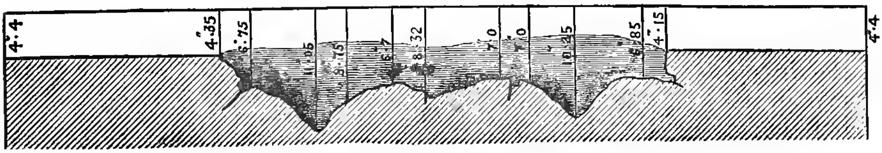


FIG. 6.
SECTION AT A. B.

and the curved form of their sides. This strange phenomenon perhaps throws some light on an appearance which has given rise to much speculation in former rounds fired at steel-faced armour. It has always been observed that a wedge-shaped layer of steel is apparently separated radially round the indents, and, in early experiments, it was thought that a thin part of the steel face, the absolute uniformity of which cannot always be guaranteed, had been struck. The frequency of the appearance, however, negatived the theory, and the denuding of this plate seems to show what probably happened in other instances; the wedge-shaped layer of steel being in fact, a portion of the surface or covering of the craters now removed. It is wonderful to contemplate the intricate molecular movement which must have been going on under the apparently undisturbed surface of the plate, and which was merely indicated by the radial cracks which were developed, some at the time, and some considerably after the shot had struck; difficult, too, to realise the tremendous tension to which this surface was subjected, tightly stretched over the distorted metal beneath it. Yet, in spite of all this the plate had still cohesive power left to withstand successfully the shock of the first 38-ton projectile." Major O'Callaghan suggests the following explanation of the phenomena exhibited :—" When a shot strikes and is arrested by a plate, the metal its point or head displaces must go somewhere. In a wrought-iron plate, it is (we believe) driven forward in a cone in front of the shot, the 'bulge' at back presenting the well known features of a pronounced swelling, which, if the point has nearly penetrated, is cleft by star-shaped fissures. In addition to this, there is generally a high lip thrown up round the entrance of the hole, (see Fig. VII).

" In a steel or steel-faced plate the appearances are very different, there is no lip, and the bulge in rear is scarcely perceptible (Fig. VIII.) or, at all events much less pronounced, hence it is evident that the metal round the point of impact is more impeded in its efforts to escape when displaced. Now it is clear that the displaced metal must be thrust away normally to the curvature of the head of the shot, and the direction taken by the molecules is represented by the divergency rays in the figure at all angles between vertical and horizontal. A bursting strain or thrust will be set up somewhere between these two limits, and along this line there will be a tendency on the part of the metal to separate, in other words there will be a line of cleavage, Fig. IX.

FIG. VII

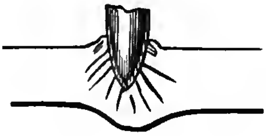
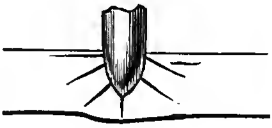
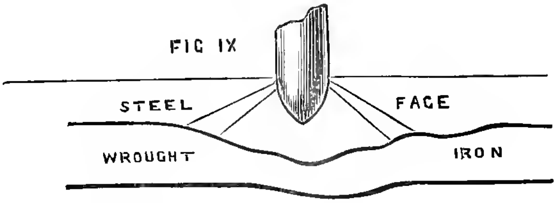


FIG. VIII.



" We should therefore be prepared to find a portion separated from the rest in the form of a cone bounded by straight lines. But it is not so. The cone is as we have seen curved in section. How is this to be accounted for ?

FIG IX



“ When any metal is subjected to a crushing strain beyond its power of resistance, it evinces a tendency to buckle or bulge outwards—this is I take it, the key to the rounded aspect of the exterior of what may be termed the ‘craters.’ The steel displaced by the advancing point is crushed and yields upwards, or buckles into the cavity caused by its separation, or partial separation from the rest of the plate; thus presenting the appearance of the rounded indented cumulus, before described.”

FIG. X

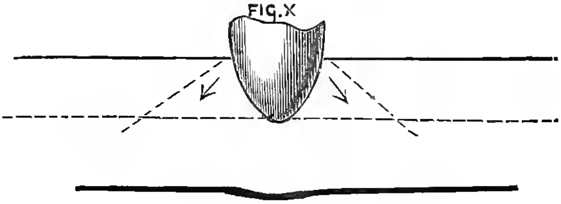
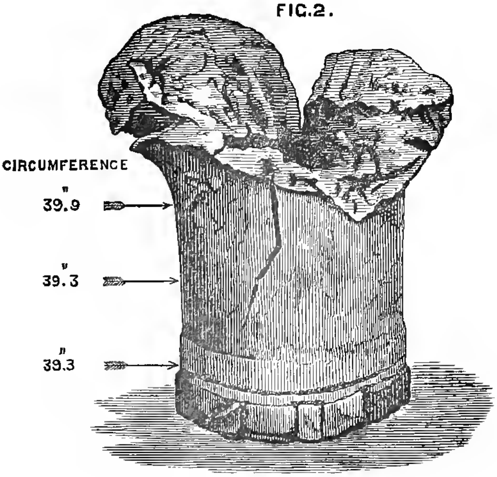


FIG. 2.



General Inglis considers that a true cone is first formed (Fig. X.), and that afterwards the shape of the shot’s head may affect the modification in form taken. Fig. 2, p. 115, shows the posterior fragment of the steel projectile fired at this plate.

The behaviour of compound and steel plates of the best description was tested in the close of this year by more remarkable trials, both because they were constructed on a much larger scale, and also because they were more strictly comparative. These took place at Spezia and also at St. Petersburg, and may be best dealt as a fresh subject.

CHAPTER VIII.

EXPERIMENTS CONTINUED.—HARD AND SOFT ARMOUR.

The Spezia Armour-plate Experiments.[1]

THE Italian authorities having adopted for the *barbette* towers of the *Italia* and *Lepanto* plates of a thickness of 48^{cm} (18·9 in.), instituted a trial of such plates, which took place in 1882, by means of the 100-ton muzzle-loading gun supplied by Sir W. Armstrong and Co. to the *Duilio*, the firing charge of this gun being sufficiently reduced for this purpose. The trial of the plates was partly competitive, for although the armour for the *Italia* had been already ordered from Messrs. Cammell, the order for the *Lepanto* plates had not been yet given, and experiments were required to arrive at the best description of plate for all future supplies of thick armour. It was, however, competitive in a limited sense, because there had been so little experience with regard to compound armour of great thickness, that neither of the representatives of Messrs. Cammell's nor Brown's firms offered their plates with confidence as fairly representing what they wish to manufacture. Further, Messrs. Cammell specially requested that samples of their plates might be tested before fulfilling their contract for the *Italia*. The plates to be tried may be described as follows:—The dimensions of all were the same, namely, 3·3^{m} × 2·62^{m} × 48^{cm} (10 ft. 10 ins. × 8 ft. 7 ins. × 18·9 ins.), the weight of each plate being nearly 31½ tons. Three kinds of plates were tried, one from each of the firms above-mentioned, namely, Cammell's, Brown's, and Schneider's.

No. 1, Cammell's, consisted of a wrought-iron foundation plate, with a steel face applied on Wilson's patent, being rolled down from a thickness of about 30 ins. to 18·9 ins. The steel, extending to a depth of about 6 ins. in the finished plate, contained about 0·65 per cent. of carbon. Mr. Wilson, who represented Cammell's firm here, stated before the trial began that he considered that owing to imperfect means the plate was not sufficiently worked, and that to do justice to the system it should have been brought down from 36 ins. original thickness.

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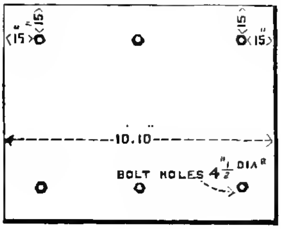
[1] *See* Engineer reports of author, Nov. 24, and Dec. 1, 1882.—The author is greatly indebted to the Italian Government, and to Admiral Albini and Admiral Rachia, for the opportunity afforded him of observing these trials.

No. 2, Brown's plate, differed from the above in having a thin rolled steel face plate of about 3 ins. thick attached to the wrought-iron foundation plate by molten steel on Ellis' patent. The total thickness of steel was the same as that of Cammell's plate, that is, about 6 ins., but it was slightly harder, containing about 0·7 per cent. of carbon. The remark as to insufficient rolling applies to this as well as to Cammell's plate. Both of them were bolted on to backing, hereafter described, by means of six bolts, each of soft steel, screwed into the back of the plates to a depth of 4½ ins., in screw holes 5¼ ins. deep, in positions shown in Fig. 10. The diameter of the bolt end was 4½ ins., on which was a plus thread on the Palliser system, 5 ins. in diameter over the thread; the bolt fitted the hole tight to keep out water, but when clear of the plate was reduced to about 3⅞ ins. in diameter, to ensure elongation in preference to yielding in the screwed part. The rear end of each bolt was secured by a washer fixed on a similar screwed thread to the front end, holding against the back face of the backing.

FIG. 10

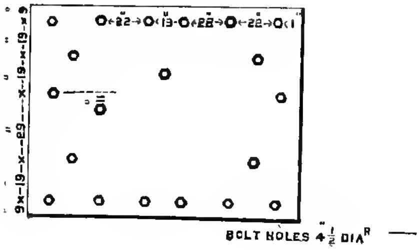
BACK OF CAMMEL'S & BROWN'S PLATES



3.—Schneider's—Creusot Company—plate consisted wholly of steel. It was said to contain about 0·45 per cent. of carbon. It had been hammered down under a 100-ton hammer from a thickness of 7 ft. to 19 ins. The face was tempered by lowering it to a depth of 6 ins. into oil. It was afterwards slightly annealed, so it is said, but no authentic information as to its manufacture is furnished by Messrs. Schneider and Co. This plate was secured by 20 screw bolts, each 4½ ins. diameter, with a thread ½-in. pitch, screwed into the back of the plate to a depth of 2¾ ins. The position of these bolts may be seen in Fig. 11.

FIG. 11

BACK OF SCHNEIDER'S PLT



The structure of the target backing and supports may be seen in Figs 1 and 2. Each plate was set in an iron frame made of three thicknesses of strips of 6-in. armour, the width of the frame being about 33 ins. and the thickness about 18 ins. These were bolted to the backing as shown in Fig. 3. The supporting frames seen in Fig. 1, were about 2 ft. apart from edge to edge. Each plate frame had a long prop at each end, extending from the top towards the front, shown in Fig. 1. On the whole it may be seen that the backing was soft though well supported. Had the frames been held together at the corners they would have been very powerful, but as it was they were of little use.

The projectiles were of Gregorini chilled-iron. They were about 44½ ins. long and 17·64 ins. in diameter, the head being struck with a radius of 1¾ diameters, and the bottom made to take the original

FIG. 4

ROUND No 1

FIRST ROUND AT CAMMELL'S PLATE

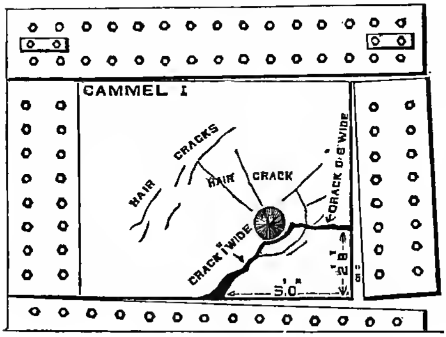


FIG. 5

ROUND No 2

FIRST ROUND AT SCHNEIDER'S PLATE

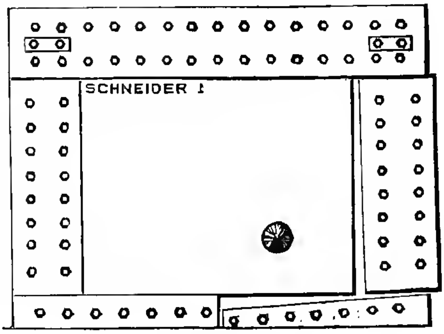


FIG. 6

ROUND No 3

FIRST ROUND AT BROWN'S TARGET

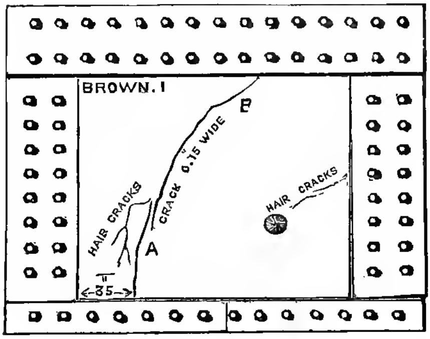
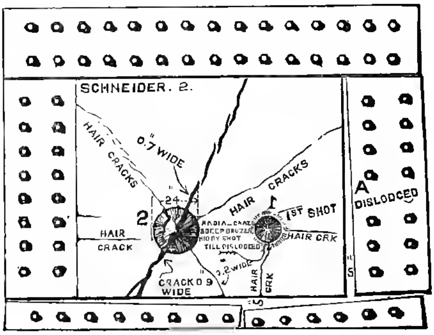
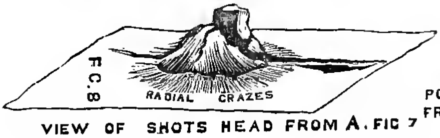


FIG. 7

ROUND No 4

SECOND ROUND AT SCHNEIDER'S PLATE





VIEW OF SHOTS HEAD FROM A. FIG 7

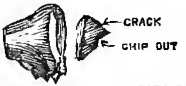


FIG. 9

POINT OF No 2 SHOT DISLODGED FROM HOLE VERY LITTLE APPEARANCE OF CHILL

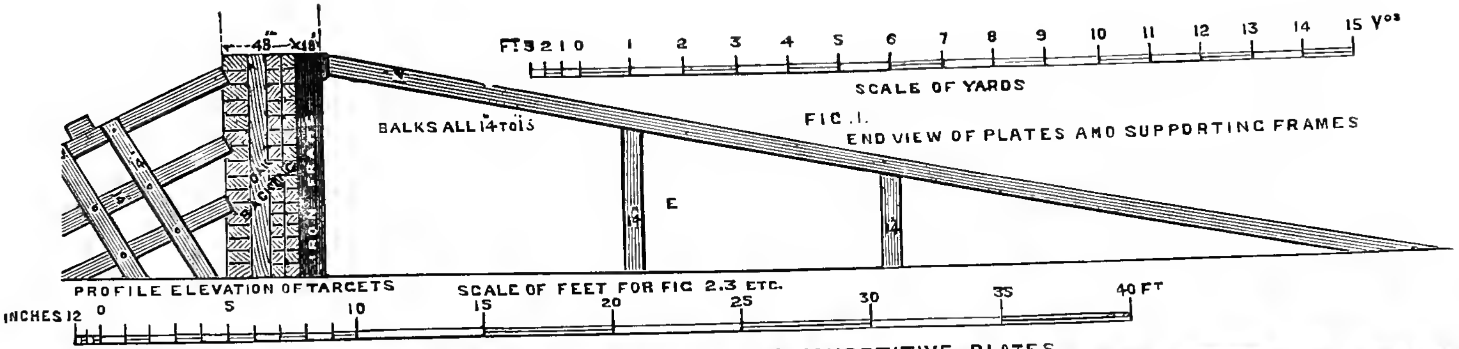
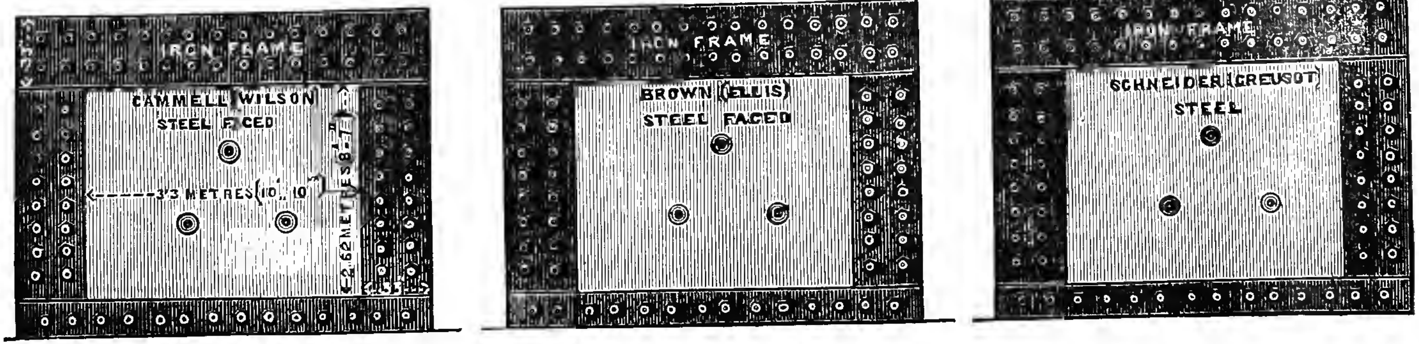


FIG. 1.
END VIEW OF PLATES AND SUPPORTING FRAMES

FIG. 3 FRONT ELEVATION OF COMPETITIVE PLATES



Elswick gas check employed with them. The weight was 896^{kg} (1975·3 lb.); with gas-check, 907^{kg} (2000 lbs.) Their quality is best discussed in connection with their effects. Speaking generally, it appeared much better than that of the competitive shot of Gregorini iron cast in our own Laboratory, these projectiles resembling much more nearly the Fingspong shot employed in the English competition.

On November 16, the firing was commenced. The first three rounds were to be fired under strictly similar conditions, the firing charge being 149^{kg} (328·5 lb.) of Fossano progressive powder, which was calculated to give the projectile sufficient energy to perforate 19 ins. of wrought-iron at the distance of the target. The spots aimed at may be seen in Fig. 3. They were struck almost exactly in each case, the shooting being admirable, in spite of a swell causing a considerable heave of the raft on which the gun was mounted, as on previous occasions. The targets stood in the order shown in Fig. 3. Cammell's plate was first attacked.

In round No. 1 the shot struck Cammell's plate on the spot shown in Fig. 4, with a striking velocity of 371·5^{m} (1219 ft.), having therefore 20,600 foot-tons energy, or 374·7 foot-tons per inch circumference, and a penetrative power equal to 19·28 ins. of wrought-iron. The plate was completely broken through in the thick crack shown in Fig. 4, while hair cracks were developed as shown in thin lines. The shot itself of course broke up, but it had held well together for a chilled projectile. No indentations made by fragments were to be seen round the portion of the head left in the plate, which projected about 5 ins. It was scored and rubbed smoother than an English shot, and felt very hot to the touch, arguing tenacity and comparative softness. The rear part of the shot was broken into four large, two medium, and many small pieces. The plate face was flat, that is, free from bending. The iron frame had yielded outwards to the extent of from 4 ins. to 6 ins. near the point of impact—*vide* Fig. 4. One long front support was thrown down, and a number of bolt heads in front broken, and some cut by shot, fragments, &c. The whole plate was set back 3 ins. at the end struck. In rear one large plate bolt was broken, and several small backing and frame bolts. The depth of the indent could only be guessed by the apparent diameter of the portion of head in plate. This is deceptive, especially with soft shot which set up.

Round No. 2 was fired at Schneider's plate, leaving the centre one —Brown's—to the last. The charge and projectile were as before. The striking velocity was 375·5^{m} (1232 ft.), having therefore 21,050 foot-tons energy, or 379·8 foot-tons per inch circumference, and a penetrative power equal to 19·49 ins. of wrought-iron. The plate resisted admirably, showing no cracks at all. The shot had behaved much as in round No. 1. The depth of indent could not be easily estimated. The fragment of shot was apparently much larger than that in the Cammell plate, projecting about 6½ ins., the plate being slightly raised or bulged in the surrounding region. The rear portion of the projectile was broken up into small pieces. The iron frame was started, opening about 5 ins. near point of impact, as shown in Fig. 5. At the back several small backing and bolt heads were snapped off, but none of the large plate bolts.

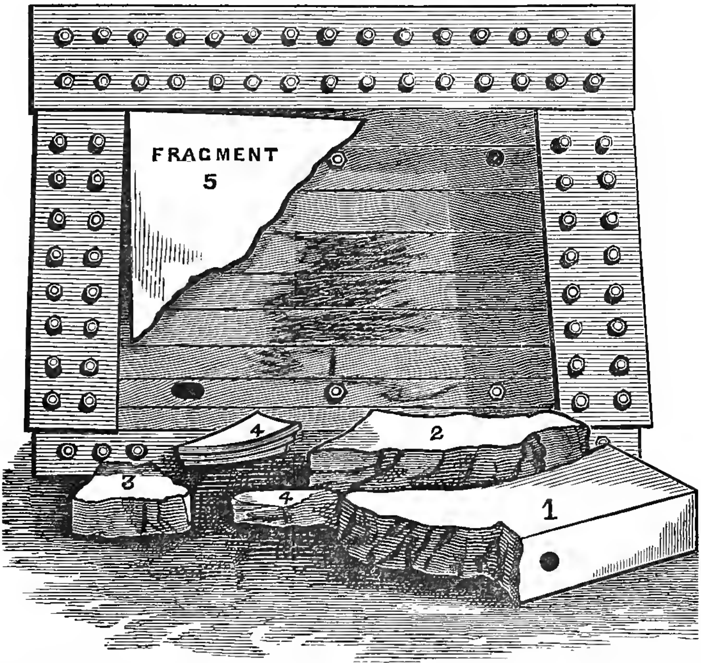
Round No. 3 was fired at Brown's plate, and struck near the desired point, Fig. 6. The striking velocity of this shot was about 372·5^{m} (1222 ft.), having therefore 20,710 foot-tons energy, or 373·8 foot-tons per inch circumference, and a penetrative power equal to 19·33 ins. of iron. This shot broke up more than those hitherto fired, leaving a smaller portion of the head in the plate projecting about 2½ ins., the indent being apparently but slight. No deep indentations were made round it, though rather deeper bruises than in the other plates. The plate showed a narrow long crack in the position shown in Fig. A B, due apparently to a sort of wave or bend-back, made by the whole plate at the end struck. Some hair cracks were also developed. The plate had bodily moved back about 2 ins., and at right bottom—corner struck—about 4 ins. The face appeared slightly concave in the region of the point of impact. At the rear some small frame and backing bolts had snapped, but no large plate bolts.

On November 17 the firing was continued. The first round—No. 4 of the series—was directed at Schneider's plate, striking near the bull's-eye at a spot shown in Fig. 7. The striking velocity was 471^{m} (15·55 ft.) giving a total energy of 33,500 foot-tons, or 326·9 foot-tons per inch circumference, and a penetration or perforation of iron equal to 24·7 ins. This shot struck near the bull's-eye, *see* 2, Fig. 7, p. 119, evidently penetrating deep into the plate, the following effects being visible :—The portion of the projectile lodged in the target measured about 18 ins. across, there being a ring of closely marked scores and dents, making a disc of about 2 ft. diameter. The plate split vertically across in lines, shown in Fig. 7 ; the plate continued to "talk" or crackle for many minutes, cracks forming and opening until the main fissure running down the left branch of fork was about 0·9-in. wide near the bottom, 0·7-in. wide a little above the shot, and the shot had opened into two parts separated about 5 ins. in the widest part, *vide* sketch Fig. 8; a ring crack also ran partly round the centre mass of the shot. The whole target was heated for about a foot round the edge of the shot, the shot itself being intensely hot. The interrupted character of the main crack near the top, as well as that of the smaller ones, was very characteristic. The right hand fork of this crack was about 0·2-in. wide. Hair cracks were opened in the position shown in Fig. 7, p. 119. These appeared to extend to a considerable depth, a very small one on the left edge visibly extending completely through the plate. The head of the shot previously lodged in the plate was dislodged by this blow, and lay in two pieces, shown in Fig. 9. The projectile had set up considerably, the depth of indent being now measurable, and proving to be only 8¼ ins., which is much less than the appearance of the fragment when sticking in the target indicated. The shot itself was obviously of a very different character from our own service Palliser projectiles, being probably softer, the chill extending only to a depth of about 1 in., and the metal yielding as no English service chilled shot will yield. At the same time it is possible that it is a more formidable shot against hard armour, from its tenacity being apparently considerably greater than that of our own. In short, the disappointment felt in the behaviour of the Gregorini shot when fired in our English competition in 1877 was in a measure explained now in seeing its performance here. Probably, however, this projectile would set up, and so fail to give very good results when required to perforate soft iron nearly a match for it. It will be seen that two hair cracks now showed themselves extending from the point of impact of the first round. The side frames were sprung wider open on the left, *vide* Fig. 7, p. 119. The shot hole will be seen to be of considerably smaller diameter than the shot fragment which was held in it, the edge of the latter having turned over and flattened under the mass of langridge which followed it up, the target being dented and bruised in a circle of impressions beneath it. It may be remembered that a chilled projectile in 1876 behaved in a somewhat similar way here on a larger scale. The back of the target stood well; some small bolts were detached and frames cracked, but no plate bolts were visibly injured.

Such a tremendous shock as this must inevitably perform a great deal of work on a plate. This plate may be regarded as disintegrated to a great extent, but it must be pronounced to have stood admirably. The pieces held well in their positions, and whatever might be the effect of a third round on the plate, it could scarcely be doubted that the shot would be kept out of a ship carrying such a plate, and the question may well be asked when a single plate would ever receive three such blows on service. Messrs. Schneider showed also great

FIG. 12

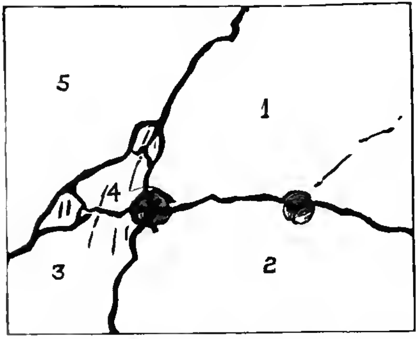
5TH ROUND-2ND ROUND AT BROWN'S PLATE



judgment in employing a large number of bolts, for it is to be observed that these cracks appeared in most cases to extend through the whole plate. What, then, would have become of the portion below the second point of impact if this entire plate had only six bolts?

Firing was continued on Monday, November 20. Round 5 of the series was fired at Brown's plate, with the same weight of charge and nature of projectile used against Schneider's plate in round 4, that is, a charge of 217^{kg} (478 lb.), and a 2000 lb. projectile of Gregorini chilled-iron; initial velocity, 478^{m}; striking velocity, $476{\cdot}6^{m}$ (1564 ft.); stored-up work, 33,910; work per inch circumference, 612·0 foot-tons; perforation of wrought-iron, 25·17 ins. The projectile struck the bull's-eye, producing the effect shown in Fig. 12, p. 123. The plate was split into six main fragments—five are shown in Fig. 13—which were all dislodged except No. 5, which remained supported by two bolts. The shot apparently had not penetrated to any great depth, but had broken the plate. Its head detached itself, *vide* Fig. 18; also the head of the previous round, *vide* Fig. 17. The wood backing in the centre was split and torn; the side frame pieces were thrown outwards at the bottom ends. The plate bolts were snapped or drawn, with the exception of the two shown in Fig. 12, holding up piece 5.

FIG.13.



PIECES OF BROWN'S PLATE ASSEMBLED.

SHOT POINTS FROM BROWN'S PLATE

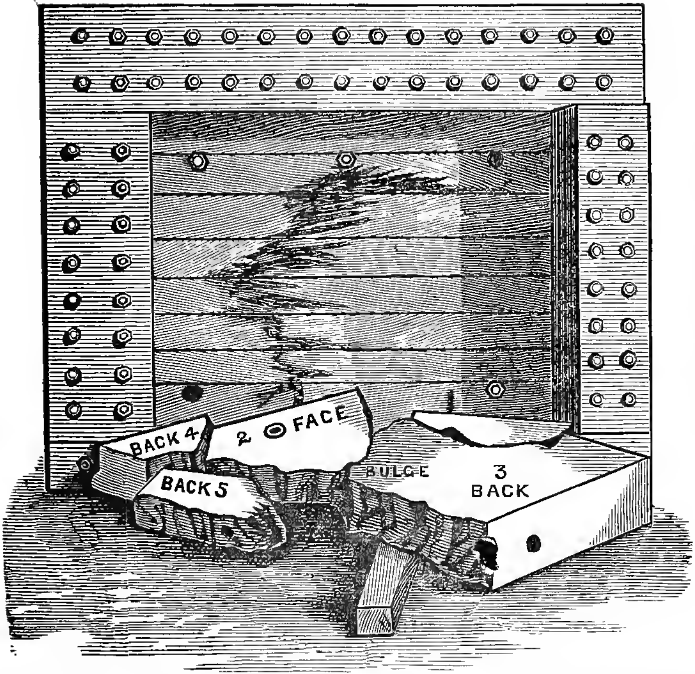
FIG 17
ROUND.1.

FIG.18
ROUND 2

Round 6 was fired with similar projectile and charge at Cammell's plate:—muzzle velocity, $479{\cdot}4^{m}$; striking velocity, $477{\cdot}0^{m}$ (1565 ft.); giving stored-up work of 33,960 foot-tons, 613 foot-tons per inch circumference, and a perforation of wrought-iron of 25·19 ins. The effects are shown on Figs. 14 and 15. The shot did not penetrate the the plate, but bulged it. It brought down the entire plate, however, snapping or drawing all bolts. In the back, No. 6 beam from the top was broken and some others started and split.

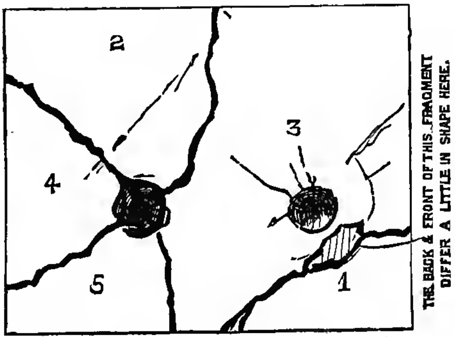
FIG. 14

6TH ROUND 2ND ROUND AT CAMMEL'S PLATE



The seventh round was fired on November 21 at Schneider's plate, against which it was decided to try the effect of a Whitworth forged steel projectile. The charge was 217^{kg} (478 lb.), the projectile weighed 942·5^{kg} (2078 lb.). The initial velocity was 471·4^{m}, the striking velocity 468·8^{m} (1538 ft.) giving a total striking energy of 34,080 foot-tons, or 615·1 foot-tons per inch circumference, equal to the perforation of 25·23 ins. of wrought-iron. The gun was aimed at the upper right-hand portion of the plate and struck it, producing the following effects :—The portion of the plate struck was broken up, some fragments being driven into the backing, *vide* Fig. 19, and part driven a little to the right, the right-hand frame being thrown aside

FIG. 15.


2
3
4
5
1
THE BACK & FRONT OF THIS FRAGMENT DIFFER A LITTLE IN SHAPE HERE.

PIECES OF CAMMELL'S PLATE ASSEMBLED.

and left hanging by its bolts nearly drawn. The top frame was thrown to the front, so as to hang over the face of the target. A part of the plate was brought down by the shot, which rebounded and lay in front, *vide* Fig. 19. This shot was set up as shown in Fig. 20, the extreme point being broken off. The original length of this shot was about 44½ ins.; it was set up to a length of 28 ins. The impression of the head and point was left on a curiously shaped piece of steel shown in Figs. 21 and 22, which was purple and blue with heat, as were two other pieces of steel plate lying close to the shot. These details should be noticed particularly, because in the contact of steels of such excellent quality it is well to note every indication of the enormous shock that must undoubtedly have been produced. The wood backing was rent and split, as seen from the front of the target. At

7TH ROUND. 3D ROUND AT SCHNEIDER'S PLATE.

FIG. 19.

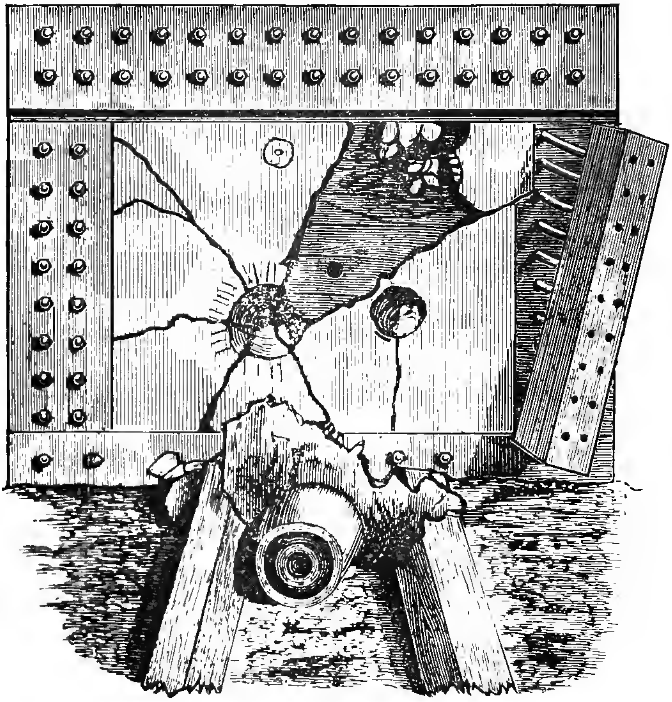


FIG 20

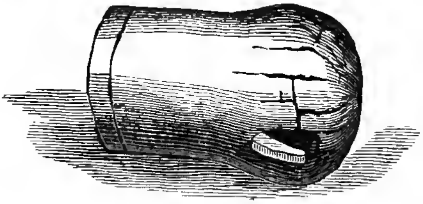


FIG 29

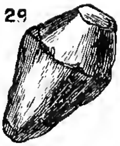


FIG 22

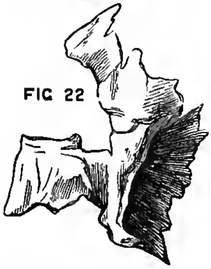
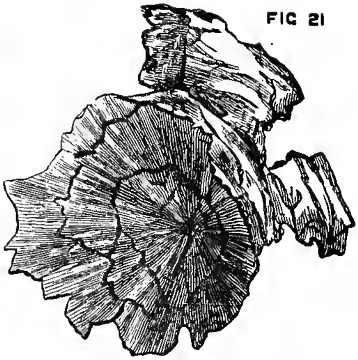
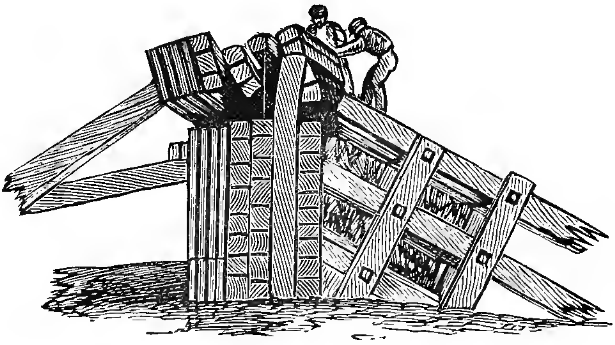


FIG 21



the back the horizontal beams, 3, 4, 5, 6, 7, 8, and 9 from the top were seen to be broken and split; some of the upper tiers of beams were lifted with the top frame. The effects are roughly shown in the small sketch—Fig. 24—taken from the bank at one end of the target. One large plate bolt was driven far out. The entire broken portion of backing beams projected about 4 ft., and long splinters much farther. After the firing it was discovered that this projectile was not a Whitworth, but one of Terre Noire manufacture sent over from San Vito by mistake. It certainly resembled Whitworth's very closely, having a point inserted, and behaving very differently from the competitive Terre Noire shot supplied to England.

FIG. 24



It was thought that if the target props were looked to, the effect of one more shot might be tried with advantage, and for this purpose a cast steel Italian projectile was selected. The same charge, 478 lb., was employed. The projectile weighed 952^{kg} with gas check $963{\cdot}5^{kg}$ (2124 lb.). The striking velocity was 461^{m} (1512 ft.) This gave a total striking energy of 33,670 foot-tons and 607·7 foot-tons per inch circumference, equivalent to the perforation of 25·08 ins. of wrought-iron. The gun was aimed at a bull's-eye made on the left top portion. The shot struck the portion of plate close to the edge, driving it over as shown in Fig. 25, the shot burying itself in the backing. The natural effect of such a shot was to render the whole structure a wreck. Eventually the shot was extracted, and found to be broken. It had received a more severe blow than was probably supposed by most of those present. The posterior fragments appeared to be of inferior quality, but the fracture and appearance of the head was very good—*vide* Figs. 27, 28. This is due, no doubt, to the fact that this projectile had been tempered in oil as far as the head extends.

FIG. 25

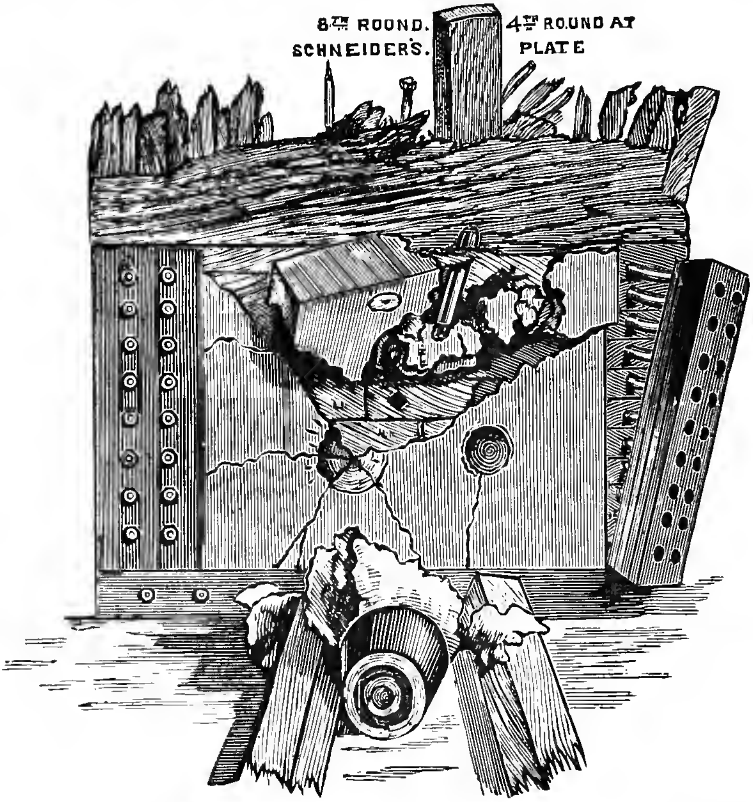

8TH ROUND.
SCHNEIDER'S.
4TH ROUND AT
PLATE

FIG. 28

FIG. 27

For more ready reference is given herewith a table of charges, velocities, &c., of the M. L. gun :—

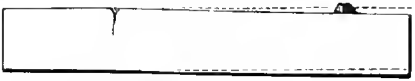
No. of round.	Fired at	Charge, weight of.	Projectile, weight of.	Initial velocity. metres.	Striking velocity.		Striking energy. foot-tons.	Striking energy per ton of plate. foot-tons.	Work per inch circumference, foot-tons.	Equivalent perforation of wrought-iron, inches.
					Metres.	Feet.				
1	Cammell.	149 kg. (328·5 lb.)	907 kg. (2000 lb.)	377·5 ?	371·5	1219	20,600	654·0	371·7	19·3
2	Schneider.	〃	〃	377·8	375·5	1232	21,050	668·2	379·8	19·5
3	Brown.	〃	〃	374·8	372·5	1222	20,710	658·5	373·8	19·3
4	Schneider.	217 kg. (478·3 lb.)	〃	476	474	1555	33,500	1064·	605·0	25·0
5	Brown.	〃	〃	478	476·6	1564	33,910	1076·	612·0	25·2
6	Cammell.	〃	〃	479	477	1565	33,960	1078·	613·0	25·2
7	Schneider.	〃	942·5 kg. (2078 lb.)	471·4	468·8	1538	34,080	1081·	615·1	25·2
8	Schneider.	〃	963·5 kg. (2124 lb.)	464	461	1512	33,670	1069·	607·7	25·1

The general character of the experiments reminds a reader of those conducted at Spezia in 1876. There was the same strictly comparative trial, each maker's plate being subjected to the same test, round after round. Whatever may be said to the contrary, there is no doubt that the Spezia experiments of 1876, were the immediate cause of steel coming into our own armour instead of wrought-iron. To consider the chief points in succession—

Plates.—Messrs. Schneider's plate was an excellent one. After receiving 122,300 foot-tons energy there remained a considerable portion of the plate and a considerable measure of protection on a great part of the target. Three particulars in which the Schneider plate had a great advantage may be noticed :—(1) The number of bolts; (2) the arrangement of bolts; (3) the tempering of the plate. As to the number of bolts, it should be noticed that a paper was originally sent to the firms supplying the plates, in which a backing was specified, that only allowed of three vertical rows of bolts. Messrs. Cammell and Brown on this fixed their six bolts. Messrs. Schneider, however, objected to the paucity of bolts, and so the backing was altered to meet their requirement. Messrs. Cammell and Brown might undoubtedly have done the same. They may be considered to blame for not doing so. The object, however, is not to review the makers, but their plates, and it is obvious that these are made to appear at a great disadvantage when the bolts are so few that fracture causes the pieces to fall down in front of the target, instead of being still held up as in the case of the Schneider. (2) The distribution of bolts in the

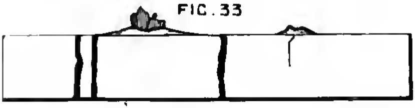
Schneider plate is very peculiar. A diagram[1] was sent to the firms concerned, on which is drawn the plate and the points to be struck, with dimensions. The Schneider plate with position of bolts is shown in Fig. 11, p. 118; the front of this plate is shown in Fig. 30 as if it were transparent, showing the bolt holes through it, the dotted circles being the spots marked to be struck. The bolt holes, it will be seen, are in irregular positions, obviously adjusted to meet the case of the three blows specified. This, then, is not a service condition. (3) With regard to the temper,—the plate was made in a peculiar manner. It was hammered—not rolled—down from a thickness of 7 ft. to its present thickness of 18·9 ins., and the front then tempered in oil. Plates so treated, while they improve greatly in quality, become slightly contorted, indeed, the second plate of Messrs. Schneider, which was lying on the ground, showed evidence of this. It is said to have measured only 462mm, or 18·2 ins., instead of its full 18·9 ins. in thickness at the ends, and that it thus projected slightly in the face; and it was suggested confidently by the English makers that it had warped from the true position shown in an exaggerated way by the lines A A, C C, in Fig. 31 to that shown by B B, D D, and that in

FIG. 32



BROWNS PLATE AFTER 1ST BLOW

FIG. 33



SCHNEIDER'S PLATE AFTER 2ND BLOW

FIG 31

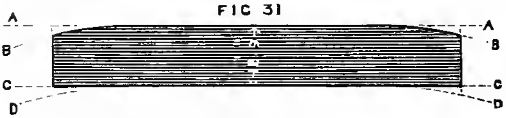
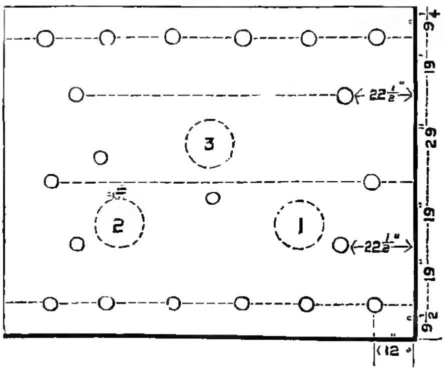


FIG. 30



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[1] In the author's possession at the present time.

order to fit fair on flat backing, the portion between C C and D D had been removed, leaving the plate bounded by the faces B B and C C. This, no doubt, leaves the plate practically uninjured for this particular experiment, and beautifully tempered, but it is not a service condition. Even in a flat face of plate it would be objectionable, and it was urged that on a turret it could not be carried out; in fact, that it would be impossible to treat curved plates of any form in this way, and that as a matter of fact every single plate on the *Italia* is a curved one. Consequently Cammell must supply untempered plates, and these compare with carefully tempered ones at a great disadvantage. As to the behaviour of the compound plates, the fracture of the iron would probably have been better had there been more rolling. One peculiarity in them has been noted, namely, the existence of concentric cracks, which have already attributed to a bend back of the plate—*vide* Fig. 32—while Schneider's plate stands up and cracks radially only. It may well be questioned if a concentric crack could be produced in Schneider's plate. Fig. 32 is intended to represent roughly Brown's plate after the first round, and Fig. 33, Schneider's, after the first and second rounds. The crack in the compound plate extended apparently only through the steel face. It must be observed, however, that the plate on the next blow broke along the line of fracture marked by the crack of the first round—*vide* Fig. 13, p. 124, and Fig. 6, p. 119. Similarly, the crack developed by the second round at Schneider's plate running from the point of impact of the first may have been initiated by the first blow. Taking the whole case of the plates into consideration, further trial between them was desirable, when conditions as to bolts and tempering should be the same, and the compound plates such that no excuse or apology is to be made for them.

The next question is the projectiles.—Our Committee on Plates and Projectiles declared that chilled shot are not effective against steel-faced armour. Can anyone say this has proved so at Spezia? Look at Figs. 12 and 14, which show the effect of two blows each with chilled projectiles, one only a match for wrought-iron the same thickness as the plate, and one a match for this thickness of compound armour or steel. We tried this Gregorini iron in England in 1878, and were disappointed in the result (*vide* p. 74). The reason, if possible, it is important to trace. We tried our metal against soft wrought-iron plates. The Gregorini shot were cast in our arsenal, and so were hardly representative ones. The Finspong, which a good deal resemble them—being made of charcoal iron—behaved as shown in Fig. 34, p. 132; that is to say, they held together but set up, and so failed to penetrate as well as our own Laboratory chilled projectiles—shown in Fig. 35. The fact is that for soft plates hardness is more important than tenacity. Our own projectiles were liable to break, but not in such a way as to interfere with their penetration so much as did the setting up of the Finspong shot. On this we declared our chilled projectile to be the best. Subsequently we found them almost useless against steel-faced armour. Fig. 36 shows the effect of the chilled shot fired from the 38-ton gun against steel-faced armour on July 21, 1880 (*vide* p. 132). The striking velocity was 1504 ft., the

FIG 34

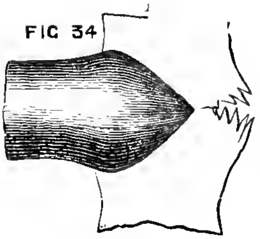


FIG. 38

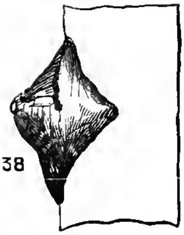


FIG 35

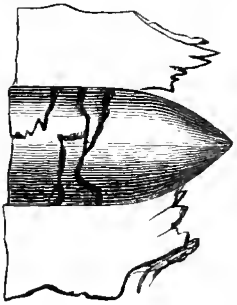
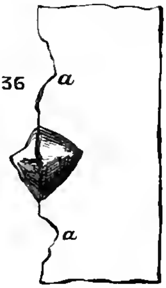


FIG 36



weight of shot 828 lb., consequently the total stored-up work was 12,980 foot-tons, or 332·6 foot-tons per inch circumference, and the power of penetration was that of about 18·7 ins. of wrought-iron. The plate was but 18 ins. thick. Compare this result with Fig. 38, which illustrates similarly the effect of the first blow on the Cammell plate at Spezia. Surely it is apparent that the greater tenacity of the Gregorini metal has held it together so as to give a more telling blow on the target in spite of the shot setting up into a mis-shapen form. The English shot, up to this time,[1] when resisted by a hard surface, flew asunder because its head was not buried in the plate, and in this position, for obvious mechanical reasons, an outward thrust comes on it which it has not tenacity to resist; the fragments then flew into a wide circle, with enough energy in them to make deep unprofitable holes, while the Gregorini shot held together and makes no such marks.

Fragments of the plates were subsequently fired at, and some conclusions, arrived at in Italy, were published in the *Rivista Marittima, May, 1883*. The principal points noticed were hardness of the steel face of the compound plates compared with that of the Schneider's, and the flexibility of the back or foundation. Penetration in the Schneider's may be effected in a greater or less degree, according to the power of the shot (indeed, in softer plates, such penetration may be so deep as to amount to complete perforation). On the other hand, the steel face of the compound plates is hard enough to resist penetration proper. The yielding nature of the backing in the abovementioned experiments was thought to tell much against the compound plates which bent bodily more than the steel. On a ship's side, they would be more rigidly supported.[2] These conclusions at the time appeared to be sound, but need some modification when variation occurs in the conditions of trial. The Spezia trials are always on a clearly defined plan. When comparisons are made, the conditions are strictly comparative; conclusions on the elements under trial are therefore sound generally. It will be seen in a subsequent experiment at Shoeburyness how thoroughly borne out was the conclusion that the behaviour of compound plates is greatly effected by the nature of the backing (*see* pp. 143 and 144).

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[1] English chilled projectiles subsequently produced some remarkable results fired against steel-faced armour at Shoeburyness.

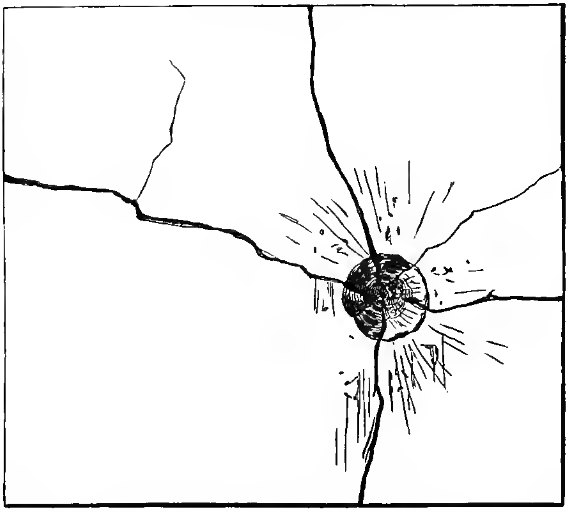
[2] *Vide* Admiral Acton's opinion quoted, Engineer, June 22, 1883, p. 475.

It is necessary, however, to be clear about the question of perforation. In the last Shoeburyness compound-plate trial (given pp. 112 and 113), discs of metal were driven out, and a kind of perforation established. This may almost appear to be contradictory to the above, and requires to be considered carefully with it. The Italian authorities appear to consider that the solid steel is locally less rigid and hard than the steel face of the compound plates. Penetration in degree may be effected in solid steel, nevertheless the solid steel as a mass is more rigid, or, as it were, has more bone in it, and is less inclined to bend; consequently rigid backing is less necessary to solid steel than to compound or steel-faced armour.

Armour Plate Trials at St. Petersburg.

On November 24, 1882, at Ochta,[1] near St. Petersburg, a Schneider and a Cammell compound plate, each 8 ft. long by 7 ft. wide by 12 ins. thick, weighing about 12¼ tons, were tried. Both plates were backed by 12 ins. of timber placed horizontally and two ¾-in. iron plates supported by diagonal struts. An 11-inch Aboukoff breech-loading gun was fired at them, chilled-iron shells weighing 553½ lbs. (English) being employed, made at Perm in the Ural. The full charge was

FIG. 1



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[1] *Vide* Engineer, December 8, 1882, p. 423, and April 6, 1883, p. 264.

132 lbs. (English) and velocity 1506 feet. The shot broke up and the Schneider plate was broken into five pieces at the first round, but it was not detached from the backing, being held up by 12 bolts (*vide* Fig. 1, p. 133). Two more rounds with reduced charges, 81 lbs., (English) were fired, the striking velocity in each case being 1167 ft.; the plate then being further split up, about one quarter of it being detached from the backing (*vide* Figs. 2 and 3, herewith), the projectile

FIG. 2

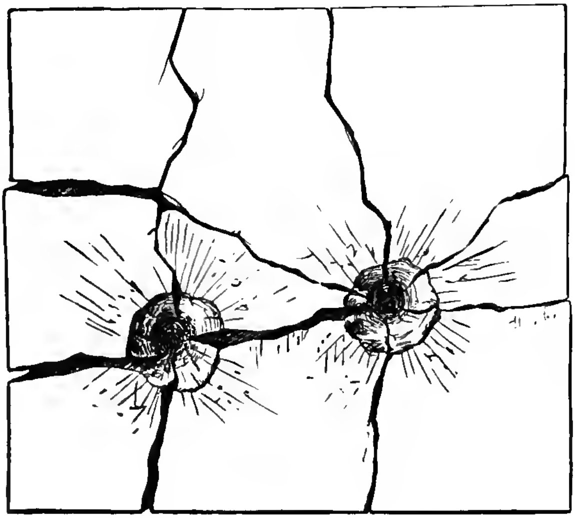
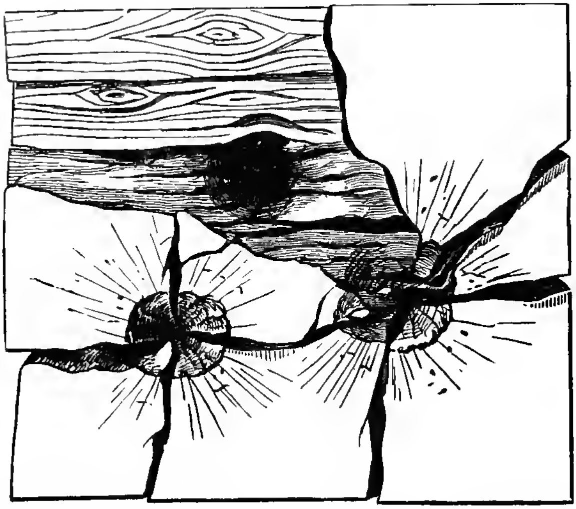
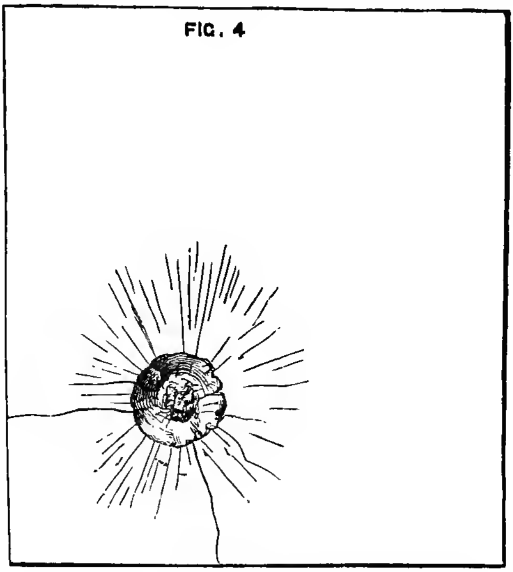


FIG. 3



passing on to 740 yards in rear of the target. A round corresponding to the first fired at Schneider's plate, was then fired at Cammell's plate with 132 lbs. (English) charge, velocity 1506 feet, the shot broke up, leaving the head lodged in the plate; the plate had some slight cracks in it, concentric and radial, but was intact (*vide* Fig. 4, herewith).

FIG. 4



A second round was fired at this plate with a reduced charge of 81 lbs. (English), when the plate became detached from the backing falling on its face. This may be attributed to the fact that it had been held by only 4 bolts. Face cracks were produced and a piece detached to a depth of 5 inches, which was attributed to a bad weld in the iron, the junction of steel and iron occurring at 4 inches depth from the face not 5. The back showed a bulge ¾-inch high at first point of impact, but no other perceptible bulges or cracks. The stored-up work in the first round at each plate was 8704 foot-tons, that is, 710·6 foot-tons per ton of plate, implying a power of perforation of 16·3 ins. of iron. The subsequent rounds at each plate had 5228 foot-tons energy, and a power of perforation of 12·21 ins. The plates then were fairly tried, the Cammell standing much better than the Schneider plate. It is to be regretted that Cammell's bolting in this case as well as at Spezia was insufficient.

On March 8, 1883, Cammell's plate was again fired at with the same charge as the second round, with much the same results, namely, a few more face cracks and another piece detached from the face. A fourth round produced similar effects, that is, a few more cracks and another piece of the face detached and the point of the third shot dislodged; Figs. 1, 2, and 3 pp. 136 and 137, show the Cammell plates after the 2nd, 3rd and 4th rounds. The striking energy or stored-up work in each round, except the first, at each plate being 5,228 foot-tons, or 426·9 foot-tons per ton of plate, the Cammell plate had borne

Fig 1.

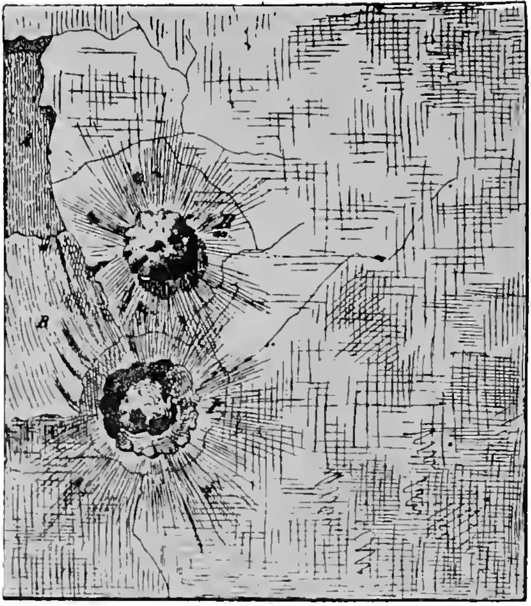
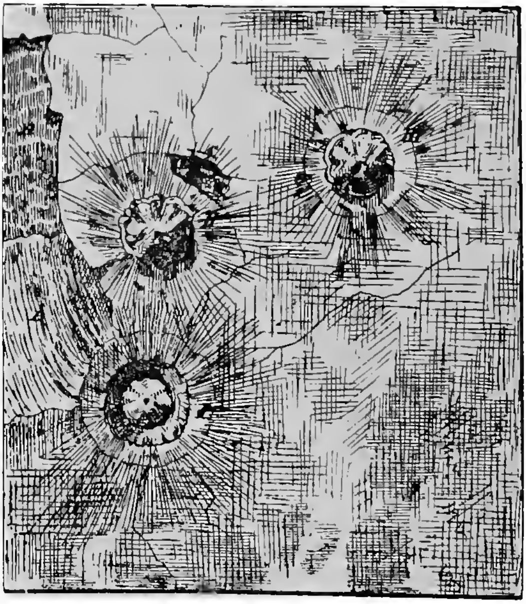
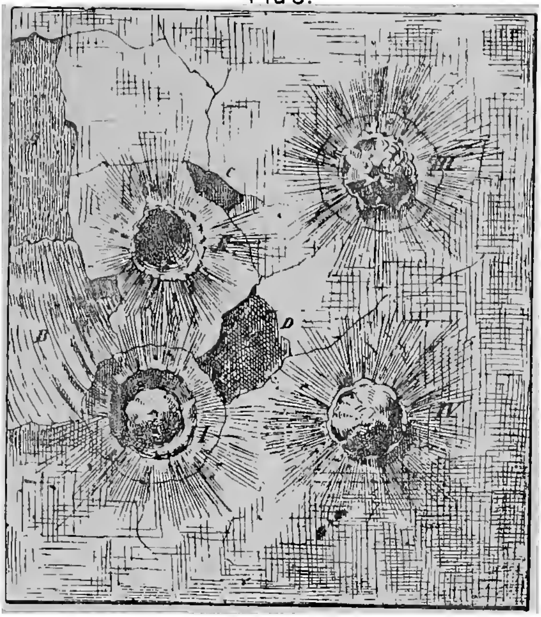


Fig 2.



Fic 3.



a total amount of 24,388 foot-tons or 1991·3 foot-tons per ton of plate, and the Schneider 19,160 foot-tons, or 1564·4 foot-tons per ton of plate.

In this case, the Cammell-Wilson plate had defeated the Schneider, reversing the results obtained at Spezia, but in justice to Schneider, it must be pointed out that the scale is a much smaller one, and that success on a large scale is specially important.

On April 5, 1883,[1] Palliser's improved steel jacketed shot were fired from an 80-pr. gun, against a wrought-iron plate 8·73 ins. thick (termed the Rupert plate, No. 75) at Shoeburyness. It had been employed for some Admiralty proof firing. Five 9-inch projectiles had perforated it, one with 50 lb. and two with 40 lb. charges had perforated it. Two with 30 lbs. had partially got through. The portion struck by the Palliser shot was sound and untouched for a considerable area (Fig. 1, p. 138); the projectile is shown before firing in Fig. 2, p. 138. The chief peculiar features are the sharp-pointed ribbed head, the reduced diameter, and the steel jacket over the body. The striking velocity was 1400 feet per second. A heavy projectile of this calibre (6·3-inch) might possibly be driven through the plate. This shot however only weighed 85 lbs. Its calculated perforation (t) is therefore 7·7 ins. of iron. Its energy (E) was 1155. Its energy per inch circumference (e) was 58·4. The shot not only perforated the plate, but passed on, striking an old target with considerable force.

A compound (steel-faced) 6-inch plate was attacked by Palliser and improved projectiles, and also by special shot made in the Royal

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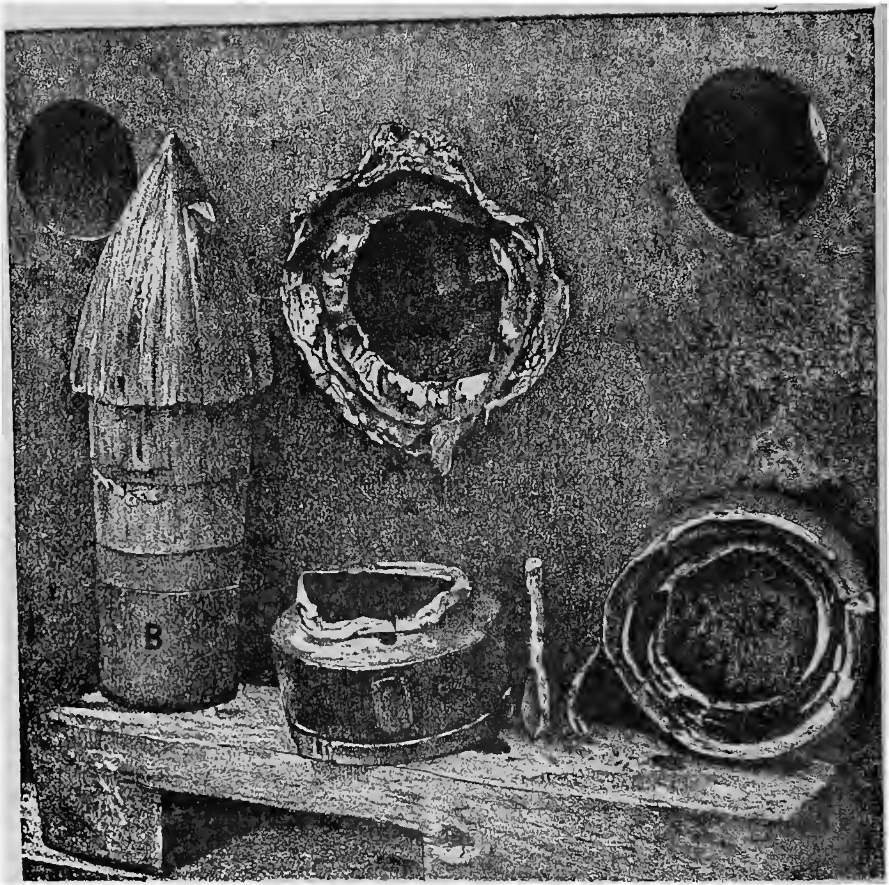
[1] *Vide* Engineer, August 3, 1883, p. 96.

Fig. 1.



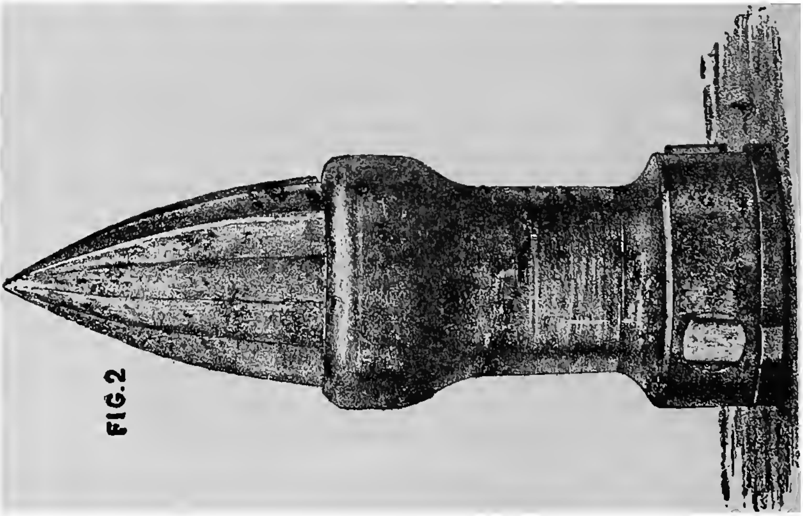


FIG. 2

Laboratory. A Palliser steel shot with steel jacket perforated the plate, two feet of timber, and entered three inches into a plate behind. Captain Palliser thought that the shot struck obliquely from appearance of hole, and breaking of shot and jacket. A second Palliser shot of chilled-iron with steel jacket was fired, it broke up badly, but it was a bad shot, being only chilled to a depth of ½-inch. The powder charge was 20 lbs. pebble, the striking velocity was only 1400 feet.

Two long pointed chilled-iron shot (being a modified form of Palliser service shot) made in the Royal Laboratory, were fired from the 80-pr. gun at the 6-inch steel-faced plate and perforated it, so that the Palliser improved jacketed shot displayed no advantage on this occasion, that made of chilled iron being bad.

Engineer Experiments on Shields fixed on Masonry.

On Tuesday, August 22, 1883,[1] an experiment of great interest, especially to England, took place at Shoeburyness. It was carried out by the Royal Engineers with a view to testing the amount of protection afforded to granite forts by iron plates. The general nature of the work (known as No. 44 target) tested is shown in the accompanying sketches (Figs. 1, 2, and 3, pp. 140 and 141).

The shields fixed on the face of portions II. and III. are as follows:—that on No. III., against which the first shot was to be fired, consists of two plates of 8 inches thickness each, of wrought-iron, sandwiched with 5 inches of wood behind each, made up of two thicknesses, that is, 2½-inch planks laid horizontally, next behind each plate, and 2½-inch planks behind them placed vertically (Fig. 3, p. 140). The dimensions of each plate were as follows: length 12 feet, height 7 feet, and thickness 8 inches. They were supplied by Messrs. Cammell. They were held in their place by six bolts, on the Palliser-English system.

The shield on portion II. consists of 12 inches of Wilson's steel-faced iron, in a plate 7 feet by 7 feet held up by four bolts, fixed inside an iron frame, as shown in Figs. 1 and 2, pp. 140 and 141. On the top of the work was laid a quantity of old broken plating, to keep the masonry and concrete from rising under the force of the blow—(*vide* Fig. 1), at portions II. and III. Structures of concrete would hardly attain their full strength for many months, perhaps years to come, and allowance must be made for this in this trial, which it will be seen was a very severe one.

The gun employed was the 80-ton gun, M.L., which was mounted at 200 yards distance. One round was fired from it at portion III.—iron sandwich on granite. A projectile weighing 1,700 lbs. was fired with a charge of 450 lbs. of pebble powder, with a velocity of 1,588 feet. This implies a total amount of stored-up-work (E) of about 29,730 foot-tons, or 594·4 foot-tons per inch circumference, representing a power of perforating about 25 inches of iron. The shot was a service Palliser chilled-iron projectile, about 3 feet 8½ inches long, fired without bursting charge, the radius of the head being about 1½ inches diameter. The shot struck a point 3 feet from the bottom of the plate, and 3 feet 8 inches from the left end looking at it. The effects were as follows:— The shot cut a clean hole, passing through both plates, and breaking up during penetration, turned rather to the left, the point reaching a depth of nearly 10 feet, measuring from the front face of the iron. The plates behaved admirably, the hole being cut almost without any apparent effect in the surrounding portion of the plate. The wood was driven outwards, 5 inches of the ends of the horizontal planks being thrust out beyond the plate at the left end, and 3 inches on the right.

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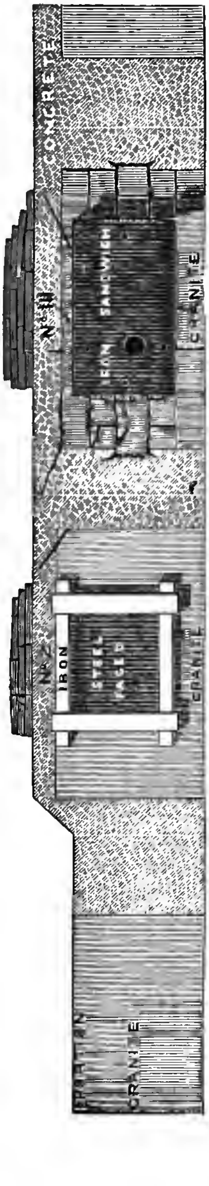
[1] *Vide* Engineer, August 31, 1883, p. 166, and September 28, 1883, p. 240.

FIG.1

OLD PLATES TO KEEP THE CONCRETE FROM RISING



FRONT VIEW OF TARGETS

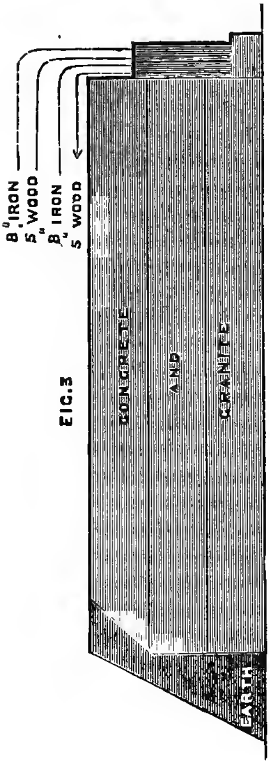


FIG.3

END ELEVATION

PLAN

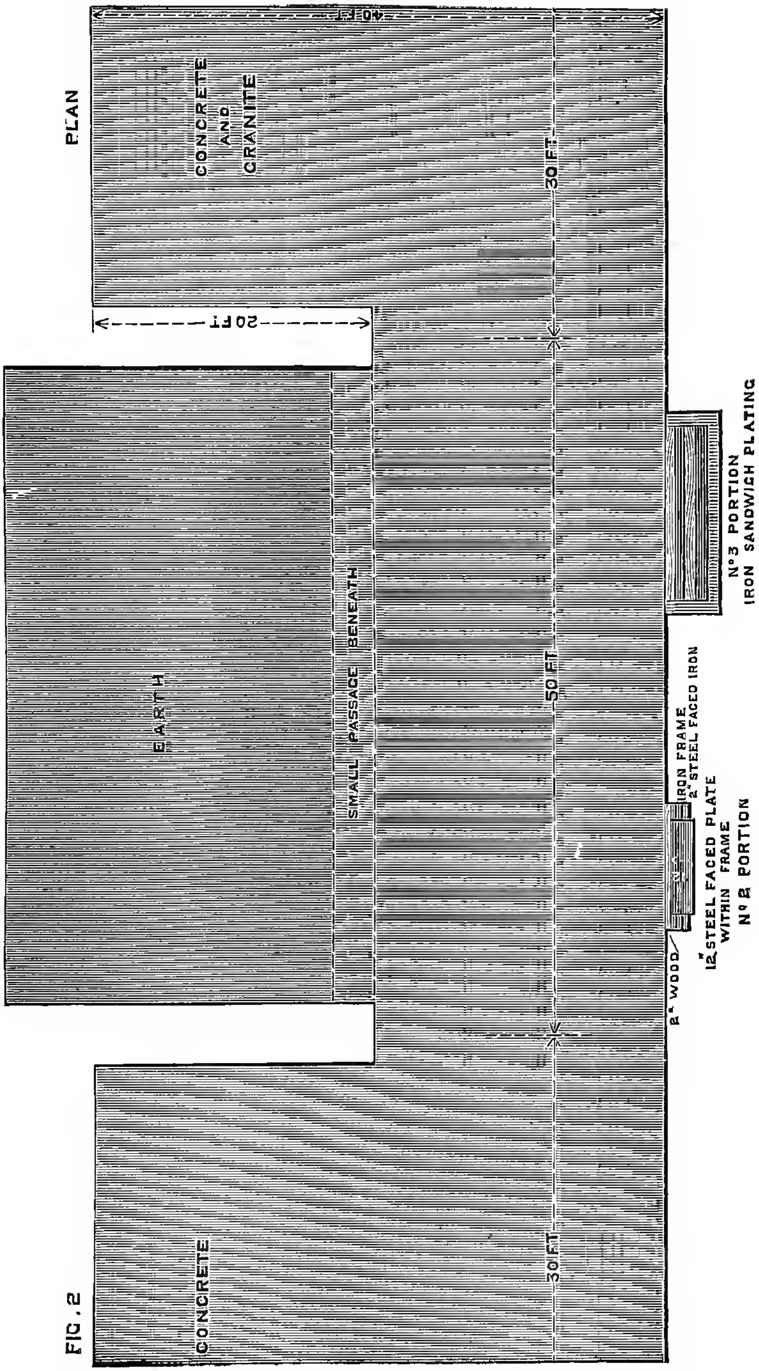

40 FT
CONCRETE AND GRANITE
30 FT
20 FT
EARTH
SMALL PASSAGE BENEATH
50 FT
No 3 PORTION IRON SANDWICH PLATING
IRON FRAME
2" STEEL FACED IRON
12" STEEL FACED PLATE WITHIN FRAME
No 2 PORTION
2" WOOD
30 FT
CONCRETE

FIG. 2

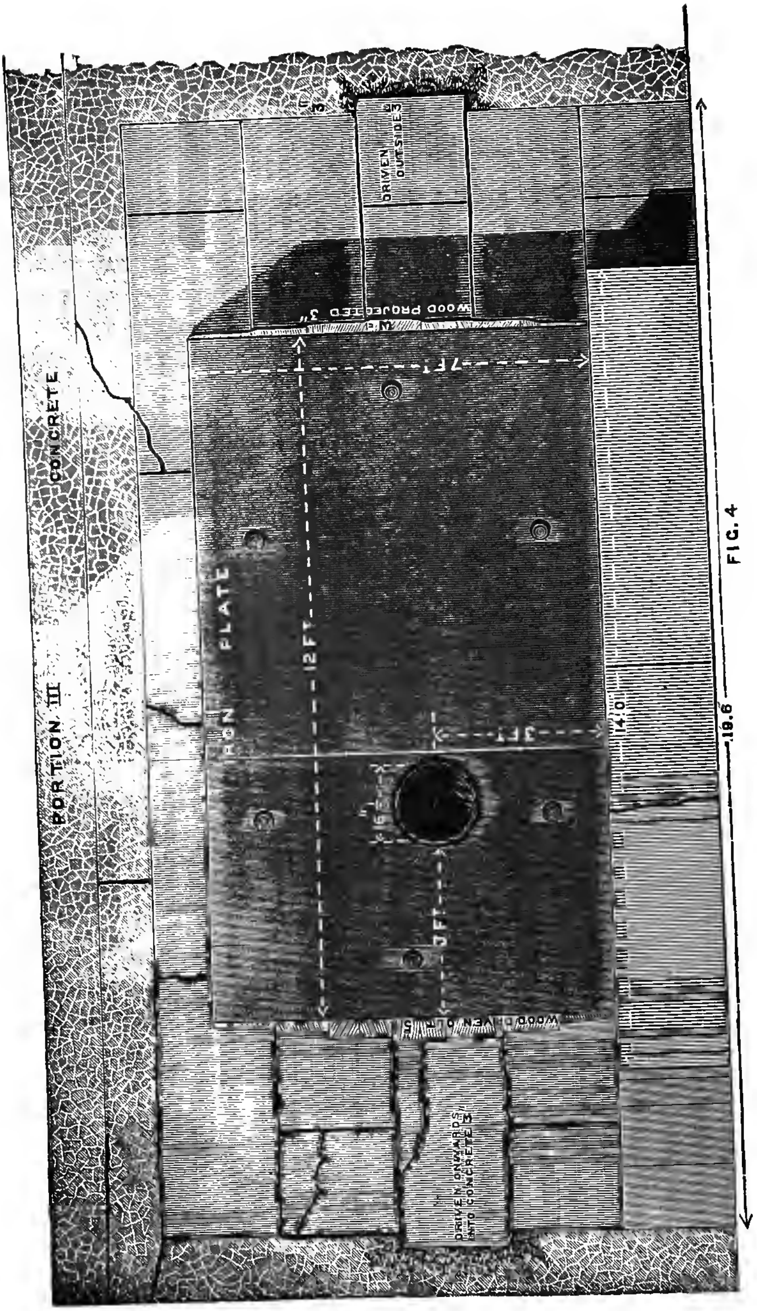

PORTION III
CONCRETE
DRIVEN OUTSIDE 3"
WOOD PROJECTED 3"
7 FT
12 FT
PLATE
3 FT
6"
3 FT
14.0
19.6
WOOD DRIVEN 3"
DRIVEN ONWARDS INTO CONCRETE 3"

FIG. 4

The granite was pulverized all round the projectile for some distance. Cracks were visible in the granite in front, as shown in Fig. 4. They will be observed to radiate from the point of impact, speaking generally. The stones of the course through which the shot passed are, like the layers of wood, forced longitudinally, left and right, projecting 3 inches at each end of the squares of masonry, Fig. 4. One or two cracks also were visible in the brickwork lining of the small cross passage behind the part struck. The bolts do not appear to have suffered, and the general structure shows little effect beyond what is here mentioned. (Fig. 7, herewith shows the projectile with the pieces assembled after recovery).

A velocity of 1,100 feet ought to be sufficient to enable this projectile to perforate 16 inches of iron alone.

England is the only Power that has employed wrought-iron to any considerable extent in coast forts, chilled cast-iron having come in generally abroad. An experiment, therefore, that shows that wrought iron behaves well is specially satisfactory to us as a nation, and surely this is the case here. The iron has offered a great resistance, and it has suffered only locally. The latter fact is, of course, important as affecting the further powers of resistance of the fort. A shield to resist repeated blows of the 80-ton gunshot must of course be exceptionally strong. When it yields it yields locally, and leaves still a good front protection.

The second round was fired on September 11, at portion II., the steel-faced plate, &c. The projectile was in this, and in every other case, a Palliser shot weighing over 1,700 lbs., the striking velocity being something under 1,600 feet. The effect is seen in Figs 1, 2 and 3, herewith), which show the plate, and in Fig. 4, p. 144 which shows

FIG. 3

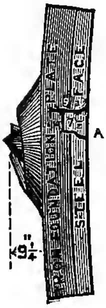
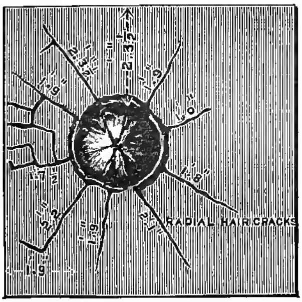
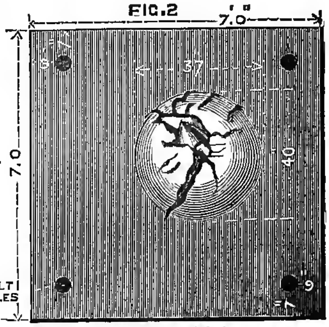


FIG. 1



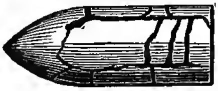
STEEL FACE
CAMMELLS(WILSONS) COMPOUND PLATE
FRONT VIEW REMOVED FROM PORTION II

FIG. 2



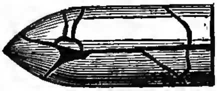
IRON BACK
CAMMELLS(WILSONS) COMPOUND PLATE
BACK VIEW

FIG. 7



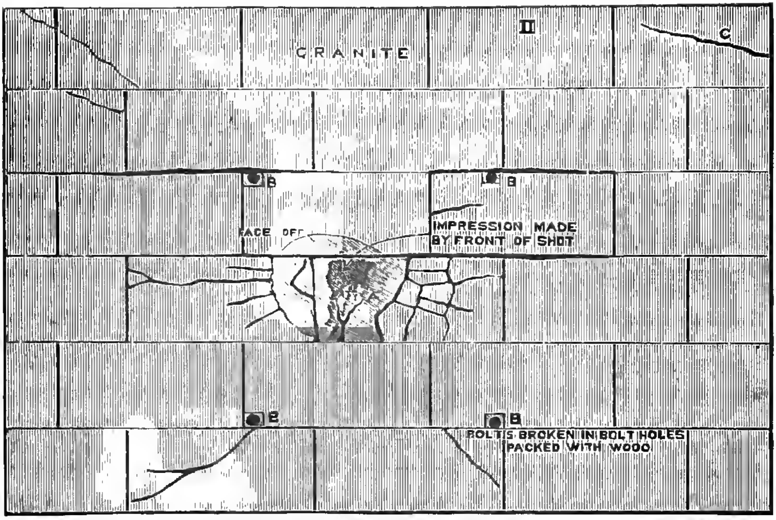
SHOT FROM WROUGHT IRON PLATE. PORTION III

FIG. 8



SHOT FROM GRANITE PORTION I

FIG 4


GRANITE
II
C
B
B
FACE OFF
IMPRESSION MADE BY FRONT OF SHOT
B
B
BOLTS BROKEN IN BOLT HOLES PACKED WITH WOOD

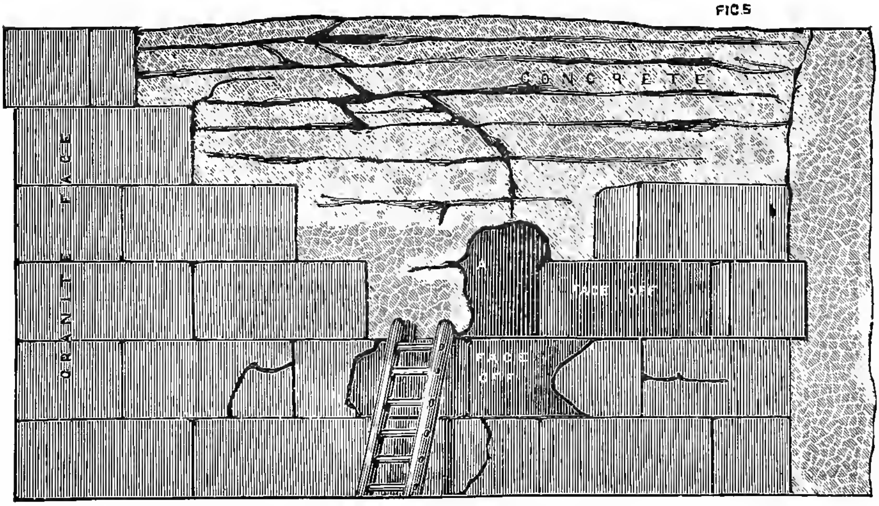
SHOWING PORTION II AFTER REMOVAL OF FRONT COMPOUND PLATE

the masonry behind it. It will be seen that the plate stood wonderfully well. The shot broke up, its head being fixed in the plate.—(*see* Figs. 1, 2 and 3, p. 143). The plate was bent and bulged, the bulge and shot being pressed unusually flat against the masonry supporting the plate. There were great annular rents immediately round the shot, where much violent work must have been done, the radial cracks were nearly all fine hair cracks—the depth of the most important may be seen in Fig. 3. The bolts stood well, holding the plate up. They were subsequently broken to enable the back of the plate and masonry to be examined. Fig. 4 shows the granite with the indentation and cracking made by the blow. This, it may be seen, is very slight, the deepest impression is that made by the shot point at A. The spring of the plate has opened the joints at the upper bolts B B, and if the side view (Fig. 3) be examined, it will be seen that a tremendous strain must have fallen on these bolts. Crack C was produced by the first round fired at portion III. Hence the cracks in the masonry, as before, nearly all radiate from the point of impact.

Taking this round as nearly the same as No. 1, it may be said that about 30,000 foot-tons work have been delivered on this shield, and that a compound 12-inch plate has, under the conditions described, borne the blow of a shot capable of perforating about 25 inches of iron. Taking the plate as weighing 10½ tons, the shot was 2857 foot-tons per ton of plate. Of course the plate backed by granite was in a very different position from one forming the chief mass of a shield. This one was only the face of a mass of masonry. Nevertheless, the blow is an enormous one, and the performance must seem extraordinary under any circumstances.

How is this to be accounted for? The natural suggestions are inferiority in shot, special excellence in plate, or special support given to this nature of plate by hard backing. There does not appear to be any reason to call the shot bad. The plate is certainly excellent, but probably the last-named cause told most—that is to say, that very hard backing specially brings out the powers of steel-faced plates. This supports the opinion of the Italian Committee, who considered that the yielding backing at Spezia told much more against the compound plate than the steel. Anyone who looks at the indication of concentric hair cracks which are apt to be formed on compound plates will perhaps concur in thinking that the value of hard backing to this class of armour is peculiarly great. Fig. 3 may suggest what would have been the effect on this plate if the backing had allowed it to bend much more. Would not the line of rupture from the point of the shot to the cracks about A have been completed? The bulged back of the plate and the shot have received a tremendous pressure against the backing. Can it be doubted that if the backing had not been an extraordinary one the plate must have snapped across? It is not necessary to detract from the qualities of the plate, which is apparently beautiful. It would surely be impossible for any 12-inch plate to stand the blow we have to consider under any ordinary conditions. Giving it all credit for excellence, then, it is desirable to explain why it bore much more than twice the blow that would generally smash such a plate up. The following is suggested:—The plate with its hard surface and hard backing resisted the shot very sharply and rigidly; this, being a chilled shot, broke under such a shock much more easily than a good steel shot would do. In fact, under these particular conditions, a softer shot with more tenacity might have done better. Still, an enormous force was at work, breaking and tearing out rings of metal close round the shot, and actually crushing in the face of the granite behind it, and it is to be noticed that there are no detached bruises on

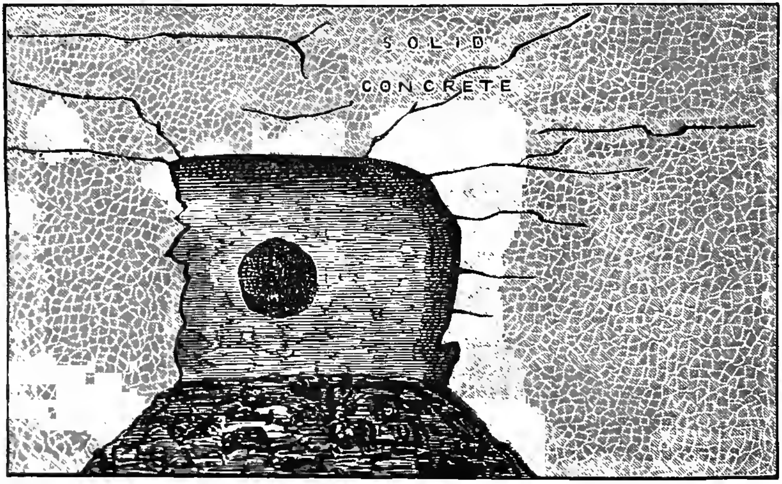
FIG.5



SHOWING PORTION I AFTER REMOVAL OF GRANITE BLOCKS ABOVE POINT OF IMPACT
SHOWING GENERAL CONDITION OF CONCRETE

the plate face, so that the work was delivered well at the point of impact. The plate had been cracked from the front to a depth of 9½ inches at the edge, as shown in Fig. 3, p. 143, but the shot was unable to bend it back and tear open the remaining thickness from the opposite side, and so the blow was borne.

FIG. 6.



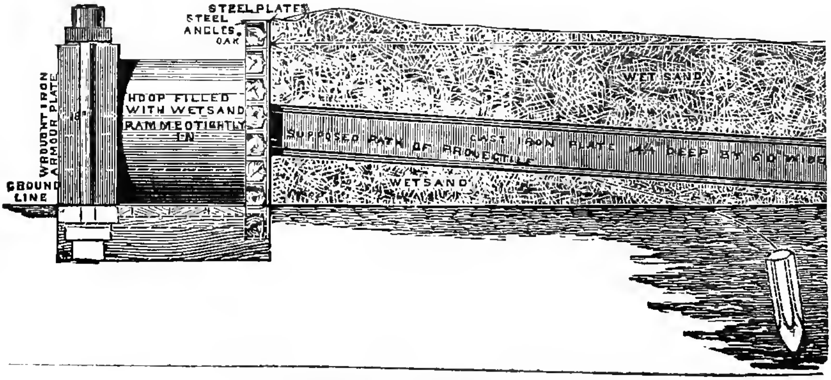
SHOWING HOLE WHERE SHOT ENTERED WITH CONCRETE IN PROCESS OF REMOVAL ROUND IT TO GET OUT SHOT
PORTION IV

JOHN SWAIN

Figs. 5 and 6 show respectively the granite and concrete portions fired at with projectiles possessing about the same energy. The shot in the granite portion struck at A, penetrating 5 feet of granite, then 13 feet of concrete, which brought its point to the second layer of granite, when it turned sharply to the right, and after passing 7 feet along the parapet, came to rest. In the concrete the shot penetrated still deeper, but did not reach the far side of the parapet.

In August, 1883, at Southport,[1] Sir Joseph Whitworth fired a forged steel shell weighing 403 lbs. from a 20-ton 9-inch gun, 29 calibres

FIG. 4.


STEEL PLATES
STEEL ANGLES
OAK
WROUGHT IRON ARMOUR PLATE
18"
GROUND LINE
HOOP FILLED WITH WET SAND RAMMED TIGHTLY IN
WET SAND
SUPPOSED PATH OF PROJECTILE
CAST IRON PLATE
DEEP BY
WIDE
WET SAND

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[1] *Vide* Engineer, August 24, 1883, p. 150.

long, at an 18-inch wrought-iron plate, strongly supported behind by an iron cylinder or hoop, forming a sort of tunnel (filled with rammed wet sand) (*vide* Fig. 4, p. 146), the plate resting against it. At the opposite end of the hoop was a 1⅛-inch plate and wood backing with steel angle-plates, and a large cast-iron bed plate rested nearly horizontally against it, buried deep in sand. The projectile struck with a velocity estimated at 1900 feet per second, having a striking energy (E) of 10,090 foot-tons, an energy per inch circumference (e)[1] of about 357 foot-tons, and a perforation $t = 19{\cdot}81$ inches. The projectile passed through the plate and tunnel, breaking up the bed plate and taking a direction shown in Fig. 4, herewith. The projectile was very little damaged, the point being slightly distorted.[2] This is a remarkable example of perforation proper. The excellence of the projectile is chiefly to be noticed.

On October 23, 1882, and on Dec. 20, 1883, deck targets consisting of 3 inches of iron or else of mild steel, were fired at Eastney, laid on in two or three thicknesses. The 10-inch and 9-inch old type Woolwich guns were employed with 70 lb. and 50 lb. charges, and with Palliser and common shells. The decks were inclined at 10° to the line of fire. Common shell could not be depended on to burst with G. S. or R. L. fuzes, and it was questionable if the effect on bursting was always greater than on breaking up, which was the invariable alternative. Palliser projectiles generally broke on impact, but produced more effect than common shells, especially those with blunt heads. Against them the deck did not afford effectual protection, though the projectiles were all deflected, even when holes were broken in the plate. The protection was sufficient against common shell that did not burst, but not always against those that did so. The Captain of the *Excellent* pointed out that common shell would probably break up and produce considerable effect against unarmoured sides of ships, while the Palliser might pass through without either exploding or breaking up.[3]

A competitive trial[4] of steel and compound plates at Amager, near Copenhagen, took place on March 20 and 21, 1884. The Figs. herewith show the plates. The nature of each round is entered near the point of impact.

The following is a brief summary of what took place:—The plates were all 6 ft. 6½ ins. long, 5 ft. high, and nearly 9 ins. thick; they were curved, so as to represent a portion of a turret 10 ft. 9 ins. inside radius. The backing was oak with iron skin and bolts. Schneider's plate was solid steel, held up by sixteen bolts; Marrel's, Cammell's, and Brown's were steel-faced; Marrel's and Cammell's being made on Wilson's patent, and Brown's on that of Ellis'. Marrel's had eleven bolts, and Cammell's and Brown's twelve each. The position of the bolts is shown by white spots. The first round at each plate was fired with a Krupp's 5·9 in. steel shell, with a striking velocity of about 1742·2 ft.; weight, 112·44 lb.; and striking energy of 2364 foot-tons. Estimating the plates at about $5\frac{1}{4}$ tons weight, this would amount to about 450 foot-tons per ton of plate. The second round at each plate consisted of a Krupp steel 10-in. shell, weighing 402 lb., with a striking velocity of 1410·8 ft., and consequently a total energy of 5551 foot-tons, or nearly 1041 foot-tons per ton of plate.

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[1] The projectile being hexagonal in cross section, this is not actually correct.

[2] It was exhibited in Geo Street, in Sir J. Whitworth's Museum, at the Iron and Steel Institute, &c.

[3] Compare with pages 47 and 48.

[4] *See* Engineer, March 28, 1884, p. 247, and May 30, p. 410.

The effect on all the plates of the first round was more considerable than might have been expected. At Ochta the lightest blows were 427 foot-tons, and the heaviest 711 foot-tons per ton of plate. At Spezia the lightest were 654, and the heaviest 1046 per ton of plate. At Shoeburyness in 1880, a blow of 541 foot-tons per ton of plate produced an insignificant effect on a steel-faced 18-in. compound plate. The results of this first round were decidedly greater than those of the lighter Spezia or Ochta rounds. This is true of the whole of the plates, and as no one could conceive for an instant that Schneider, Cammell, and Brown had all deteriorated in their manufacture, it must be attributed to the fact that Krupp's steel are better than the English or Italian chilled iron projectiles—a very natural conclusion, but one which must not on that account be overlooked. Comparing the plates together, there was at this stage little to remark. The steel of Schneider's plate appeared to be good, the lower crack exactly resembled those made at Spezia in its character; the short broken lines are very characteristic. It is considered that Cammell's plate had a harder steel face than Brown's, and that the penetration in it was less deep; but Brown's exhibited less cracking, and looks peculiarly well at this stage.

The second round of course tested the plate much more severely, being 1041 foot-tons per ton of plate, instead of 450 only. The effects are proportionally great and their shape is instructive. The shot makes an absolute breach or hole through the steel-faced plates; and no doubt had the plates been harder, more of the shock would have been distributed through them. They yielded, in a measure, locally. On the other hand, half of Schneider's plate (Figs. 1 and 2, p. 149) was bodily carried away. There are two possible reasons for this—one, that, as a mass, the steel is harder than is apt to be the case, and it is difficult, if not impossible, to make a hole in such steel; and, secondly, the flank target is a little less strong and less well supported at its outward end.

The third round at Cammell's (Figs. 3 and 4, p. 149) broke it up, being another round with the 10-in. gun. The third round at Marrel's (Figs. 5, 6 and 7, p. 150) and Brown's (Figs. 8, 9 and 10) consequently was fired with the 5·9-in. with a chilled-iron projectile. The effect appears to be as great as that of the first round; but if the fact of the plates being so far broken up is taken into account, may be said to be actually a weaker blow, but no comparison can really be made.

On the whole, the compound plates must be said to have held their own. Brown's and Cammell's appear to have held together better than Marrel's. The tests were not very well suited to exhibit the powers of

Fig. 1.—Schneider.

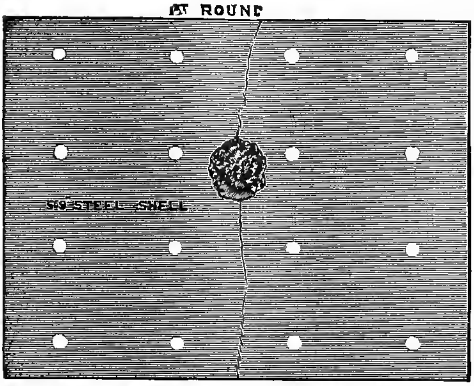


Fig. 2.

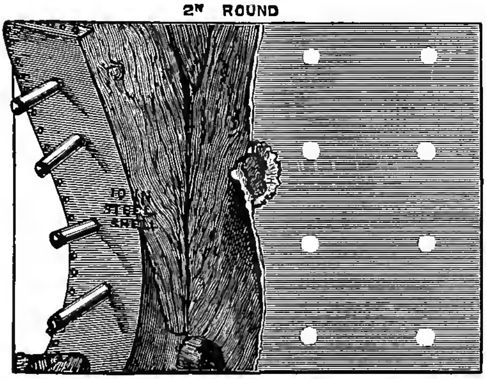


Fig. 3.—Cammell.

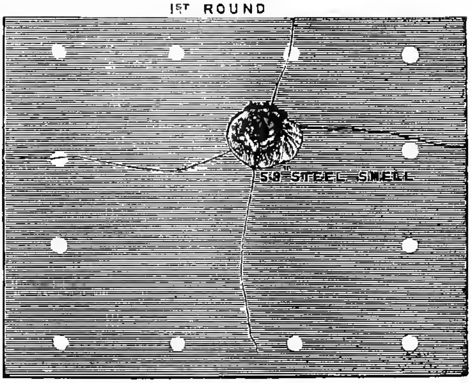
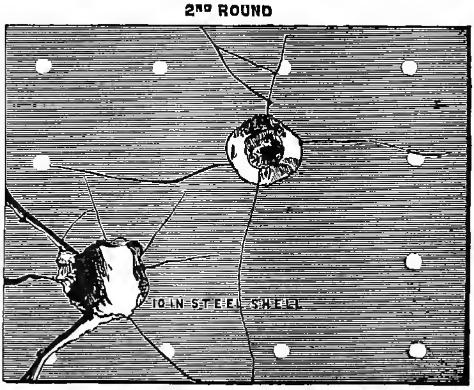


Fig. 4.



the plates, but may perhaps have answered the particular object of the Danish Government better than something which was a more even match. To exhibit the actual powers of the plates on service, the backing should correspond as closely as possible to the iron or steel structure of a ship, or to the wall of a fort. As armour becomes harder, and as the blow is transmitted more through its mass, the strength of the supporting structure is called more into play. A hole in a plate generally means a hole in the backing, and the passage of some langridge into the interior, but the movement of a shield bodily tests the supporting frames as a structure.

Experiments at Shoeburyness in 1884 were made with Palliser improved and other projectiles with specially sharp points. Some good penetrative effects were obtained, the most remarkable perhaps being that a cast-steel projectile of Hadfield's passed through a steel-faced plate without breaking up. The plate however was too far injured previously to build an opinion positively on the result, and subsequent rounds did not bear it out. Experiments also pointed to the conclusion

FIG. 5.—MARRELL.

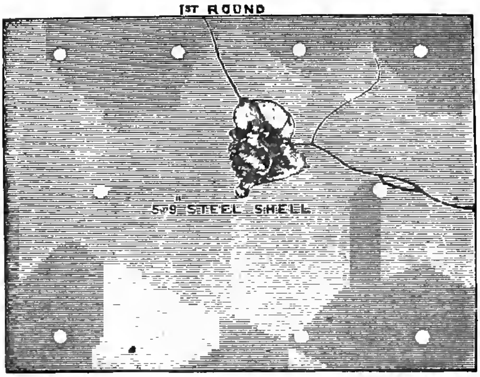


FIG. 6.

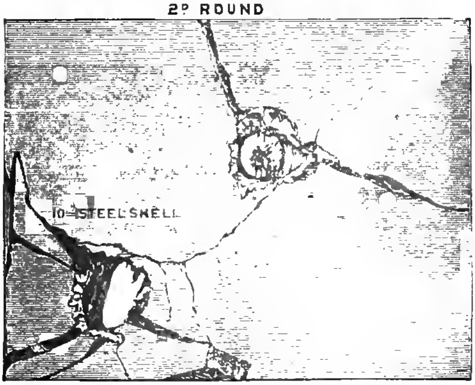


FIG. 7.

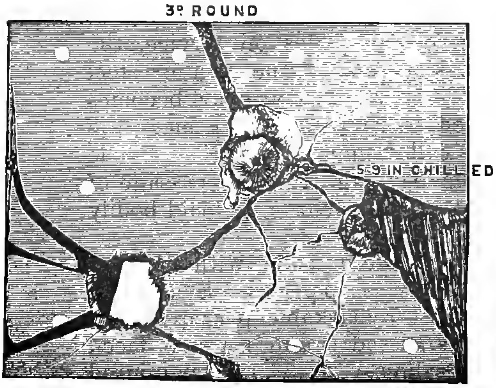


FIG. 8.—BROWN.

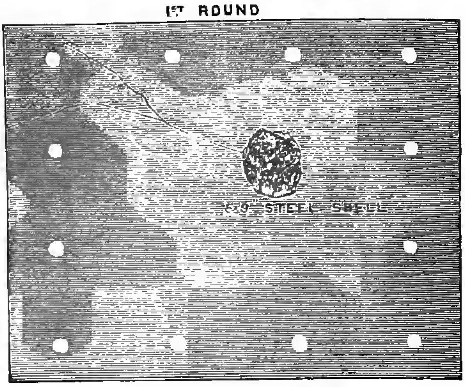


FIG. 9.

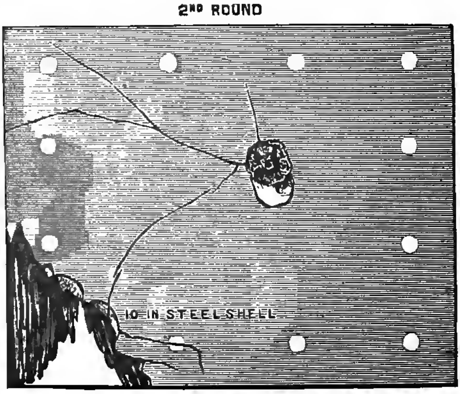
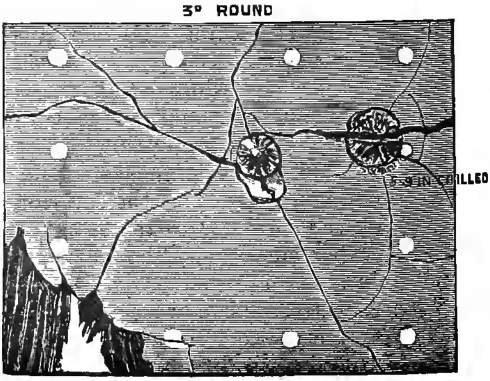


FIG. 10.



that steel-faced armour transmits the shock of the supporting structure more than wrought-iron. Nothing of a decided character can however be stated.

On October 16, 1884, a flat-headed steel projectile produced less effect on a steel-faced plate than a chilled pointed projectile.[1] In recently constructed guns the sectional density of the projectile has been much increased. For example, in the 9·2-inch gun, Mark III., $\frac{W}{D^3} = 0·488$. This, with a velocity of 2000 feet means a perforation of about 20 ins. of iron, even with the old service shaped head of 1·5 diameters radius. In the new 63-ton gun of 13·5-inch bore $\frac{W}{D^3} = 0·51$, which implies great power of perforation as well as power to keep up velocity in flight.

On Oct. 1, 1884,[2] another important competitive trial took place between the steel-faced plates of Cammell, of Brown, and the solid steel plates of Schneider at Muggiano, that is the Spezia experimental ground. Owing to the fact that Spezia had suffered severely from a visitation of cholera, very few persons were allowed to attend the trial. The following is a brief account of it:—

The object in view was to learn the effect of the fire of the new Armstrong 100-ton B. L. gun, 17-inch (43^{cm}) calibre. When discharging the best steel projectiles on the armour of the *Italia* and *Lepanto*, that is to say, to ascertain in what manner the plates would suffer when enormously over-matched. The competitive element was maintained under these conditions. The order for the *Lepanto* plates being said to depend mainly on the results of this trial. The programme was as follows:—Cammell and Brown compound and Schneider steel plates 10 ft. by 8 ft. 6 ins. by 18·9 ins. (3050^{mm} by 2600^{mm} by 480^{mm}) were mounted on frame and backing shown in Figs. 9 and 10, p. 155. One round was to be fired at the centre of each plate from the 100-ton breech-loading Armstrong gun, to be followed by a ronnd at each of the four corners of each plate from a 10-inch gun.

The 100-ton gun fired a projectile weighing 1841 lb. (835^{kg}) with a striking velocity of 1864 ft. (568^{m}) per second, making a blow of 44,340 foot-tons, or 8337 foot-tons per inch circumference, implying a calculated perforation of 30·27 ins. of iron, and taking the target's weight as 29 tons, an amount of energy of 1529 foot-tons per ton of plate. As the greatest amount of energy per ton of plate in the previous Spezia trials was 1046 foot-tons, while the calculated perforation through iron was 25·2 ins., it may be seen that this test was very severe indeed; in fact, the plates were enormously out-matched on any standard of estimation. The effects are shown on the Cammell, Brown, and Schneider plates respectively in Figs. 1, 2, and 3, pp. 152, 153, 154. The steel-faced plates obviously suffered much more than the steel one, but there appeared distinct reason to think that they had

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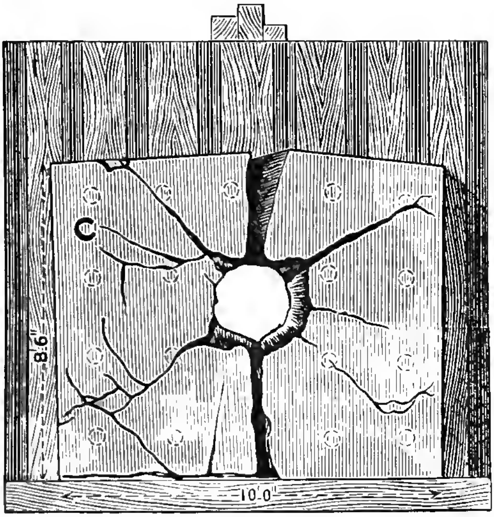
[1] It might reasonably be supposed that a flat-headed shot might *at all events hold well together* on impact against hard armour, Fairbairn having found that a flat-headed bolt resists double the crushing force required to set up a hemispherical ended one (*see* p. 4, Chap. I.) This projectile, however not only failed to crack the plate as much as the pointed shot, but also broke up more. The author cannot explain this, and would have expected the opposite, that is, he would have expected the shell to hold well together, though perhaps it might not produce a great effect on the plate. As to this, however, *vide* trials of Grüson's chilled-iron shields hereafter.

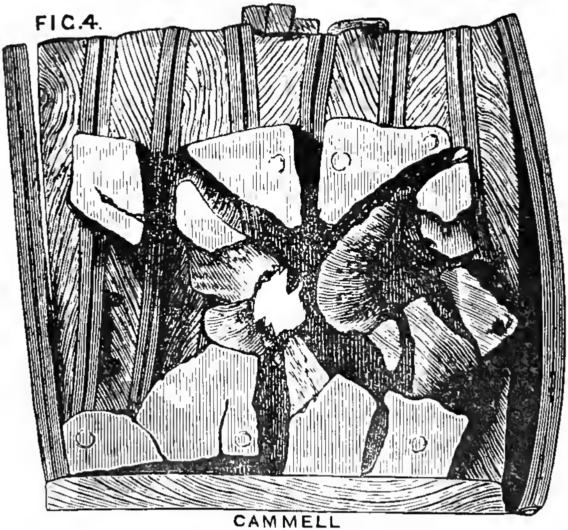
[2] Discussed in *Engineer* of October 24, 1885, and February 27, 1885. Cuts first appeared in accounts in *Annales Industrielles* and *Revue Maritime*, and *Engineering*.

FIG. 1.



CAMMELL STEEL FACED PLATE
AFTER 1 BLOW FROM 100 TON GUN STEEL PROJECTILE

FIG. 4.

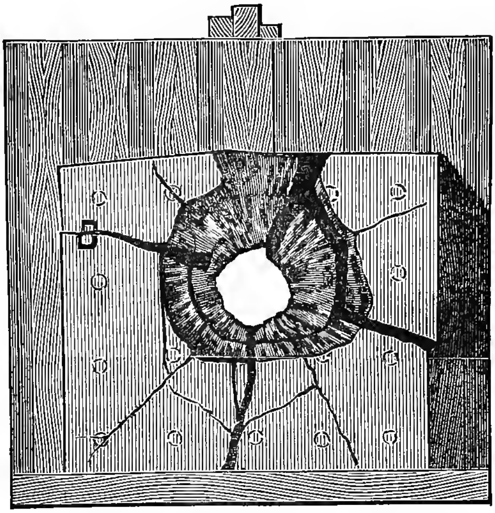


CAMMELL
AFTER 1 ROUND FROM 100 TON GUN
" 2 ROUNDS " 10.IN "

done more towards stopping the projectile than the Schneider plate, inasmuch as the shot went through the latter in a much more complete condition. Fig. 8, p. 155, shows a drawing of the fragments taken out of the butt subsequently.

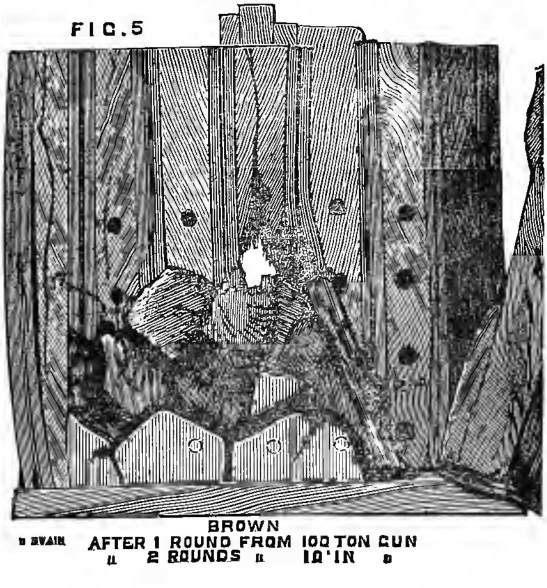
It was argued fairly enough that a shot with less velocity might have been stopped altogether by the steel-faced plate, while the steel-plate would have allowed it to pass through, and further, that the backing was much softer than a ship's side, and that this was in favour

FIG. 2



BROWN STEEL FACED PLATE
AFTER 1 BLOW FROM 100 TON GUN STEEL PROJECTILE

FIG. 5

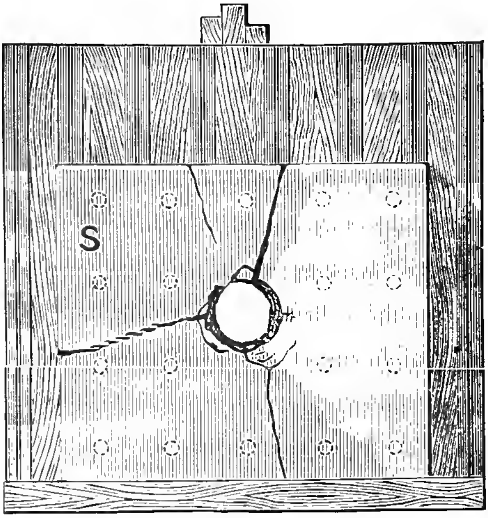


BROWN
AFTER 1 ROUND FROM 100 TON GUN
" 2 ROUNDS " 10'IN "

of the steel-plate, which, while having a less hard face, has, as a mass, "more bone in it." This argument might be fairly held at this stage of the trial. The plates were next subjected to the fire of the 10-in. gun, with a striking velocity of about 2000 ft., with the following results, on November 5, 6, and 7:—

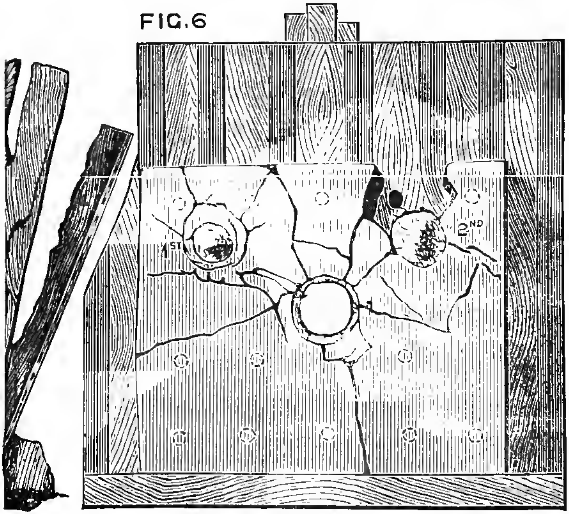
Brown's plate, penetration first round, 12·6 ins. (320^{mm}), a great part of plate detached; second round, the plate demolished to the extent shown in Fig. 5, p. 153. About three-fourths of the plate being now stripped off, further firing was impossible.

FIG 3



SCHNEIDER STEEL PLATE
AFTER 1 BLOW FROM 100 TON GUN STEEL PROJECTILE

FIG.6



SCHNEIDER
AFTER 1 ROUND FROM 100 TON GUN
• 2 ROUNDS • 10 IN •

FIG. 9.

ELEVATION OF TARGET AND BACKING

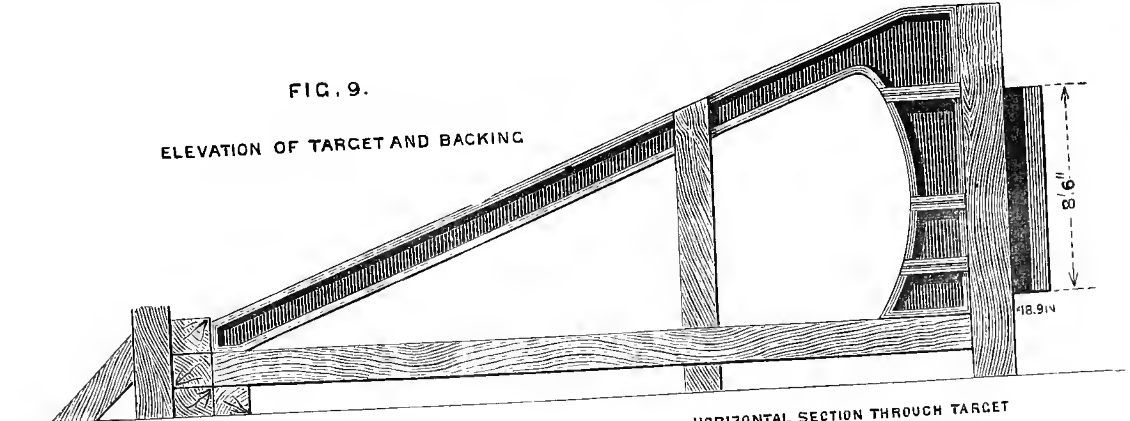
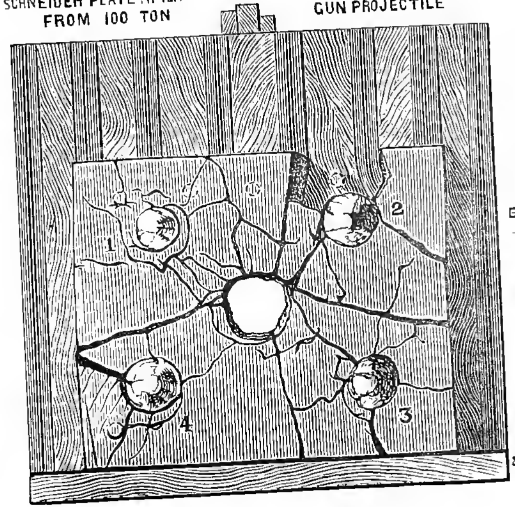


FIG. 7.

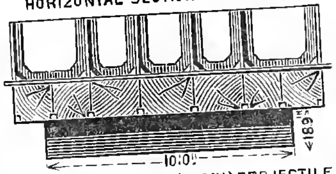
SCHNEIDER PLATE AFTER RECEIVING 1 BLOW FROM 100 TON GUN PROJECTILE



& 4 FROM 10" GUNS

FIG. 10

HORIZONTAL SECTION THROUGH TARGET



SKETCH OF 43 C.M (16·9 IN) PROJECTILE AFTER PERFORATING THE 48 C.M. (18.9 IN) STEEL PLATE SCHNEIDER

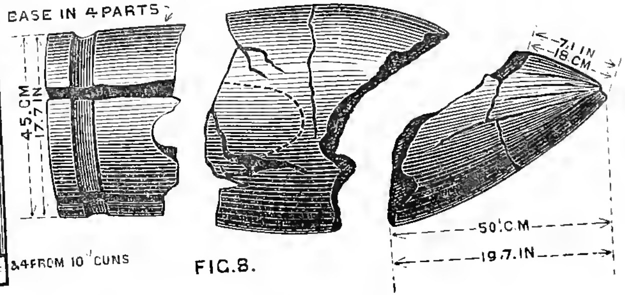


FIG. 8.

Schneider's plate then received two blows, producing cracks and fracture to the extent shown in Fig. 6, p. 154, which is given for the sake of comparison with the steel-faced plates. The shot is stated in the French accounts to have been more broken up against the steel than against the steel-faced English plates. Two more rounds were fired with the 10-inch gun, the plate at the conclusion of the programme being in the condition shown in Fig. 7, p. 155.

Cammell's plate was then attacked, broken pieces of plate being thrown off to an amount estimated at nearly 5 tons—5000 kilogs.—by the first round, and the plate being brought to the condition shown in Fig. 4, p. 152, in the second round with the 10-inch gun—a condition which made further firing useless. The Schneider steel, therefore, on this occasion won a remarkable victory, and the English plates were beaten. It may of course be argued that the steel-faced plates absorbed so much of the energy of the first heavy blow that they were afterwards in a worse position than the Schneider, which let it through more easily. The natural reply is that the makers knew the tests that would be applied, and should have made the plates to stand well under these conditions, and few would sacrifice the power of holding together shown by the steel, for the possibility that the steel-faced plate might have kept out fire, while the steel admitted it in some hypothetical case.

Is it not reasonable to say that, so far as we are able to form a conclusion from the above, it would be that on this scale our compound armour is behind Schneider's steel when exposed to direct attack? It is possible that Cammell and Brown may snatch the victory on some future occasion, especially if better means are found of working very thick plates, but at present, surely, it is only true wisdom to recognise the liability of steel-faced iron on this scale to fail to exhibit the powers of steel armour as made by Schneider. All the compound armour victories have been with thinner plates. No one can say that the compound principle, if carried out with hard and soft steel, may not be the best, but when the results above given occur repeatedly with iron, and with intervals of time sufficiently wide to develop manufacturing operations fairly well, it is idle to shut our eyes to them. Without seeing the targets themselves, there is evidence enough in the drawings to tell something to those who have seen previous results. For example, the crack in the steel below the letter S precisely resembles the long vertical crack in the Schneider plate fired at in 1882 in its character. There may be seen a succession of short, disconnected cracks, looking in the sketch like the twists in a rope, which are very characteristic.[1]

Early in the summer of 1885,[2] a proof trial of steel Schneider plates took place at Spezia of a much less satisfactory character, showing that the high quality shown in the October and November,

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[1] A comparison of this with author's sketch of Schneider's plate in 1882 trial, will give evidence of accuracy as to features of sketch.

[2] The writer has heard facts in conversation that enable him to arrive at a probable conclusion, but not circumstantial or definite.

1884, competitive plate could not always be secured. This much ought to be said in justice to the Sheffield manufacturers of steel-faced armour, but it is useless to attempt to give details from confidential or doubtful sources.

Experiments at Shoeburyness during 1885, have shown that with steel-faced armour, rigidity of backing is by all means to be secured, even at the expense of thickness in the plate.

These experiments were made with armour and supporting structure proposed for the *Admiral* class of ships. Steel-faced plates, 18 ins. thick, under the fire of the 80-ton gun, did not stand so well as 16-in. plates with the weight of the 2 ins. of plate added in the structure. Less good results were of course obtained with 14 ins. of plate and the same backing, and also with 18 ins., disposed in 12 ins. and 6 ins. sandwiched.

On August 18, 1885, at Ridsdale, Elswick, an Armstrong 9·2-in. B.L. gun projectile, weight 392 lbs., striking velocity 2166 feet, and energy 12760 foot-tons, perforated an 18-inch plate of iron and entered 6½ inches into a 7-inch plate in rear. The theoretical perforation is about 22 inches (*see* Capt. Penton's paper, R. A. I. Proceedings, Vol. XIV., p. 321).

In October, 1885, on the suggestion of Major English, R.E., a steel-faced plate about 5 feet square and 16 inches thick, was bound round by steel riband or wire laid in a large groove round the plate. The plate was fixed on granite, and attacked by the 43-ton B.L. gun. It was broken to pieces, and the fragments and riband all thrown about. Some of the riband had been much extended, but it has been objected that to act well, theoretically, the riband should be wound on to a cylinder, a condition that could hardly be carried out in armour plates. Steel riband is very costly, and scarcely likely to be used in this manner.

Some sort of review of the results obtained in the various trials of steel-faced and solid steel plates seems here called for, though it is a delicate and difficult matter.

Steel-faced armour has generally been remarkably successful when well-backed, as at Shoeburyness in 1883,[1] and when its hard surface was able to tell, as in the piece-meal trials after the Spezia experiments of 1882.[2] On a small scale it has done remarkably well, as at Ochta in 1882,[3] and often at Shoeburyness and Portsmouth.[4] Where disappointment has occurred, it has been with thick plates and indifferent support; and this statement is endorsed by experiments that are not here given. The hard face is the chief advantage possessed by the compound plate. This gives a great power to throw off oblique blows, a work constantly called for on service, but seldom tested by experiment. The compound plate has probably suffered by being compared with steel under direct attack only. The hard face has not always prevented discs being bodily torn out[5] when the backing admitted of it; in fact, this form of fracture is due to the hard face, for soft steel or iron would have probably allowed the shot point to cut through in preference. On certain occasions steel-faced armour has been fairly perforated, but it resists this action much more strongly than solid steel generally, owing to the face of the latter being softer and allowing a hard sharp point to enter it.

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[1] *Vide* p. 143. [2] *Vide* p. 132. [3] *Vide* p. 133. [4] *Vide* pp. 69, 79, 80, 99, 101, 108, 111, and 143.
[5] *Vide* p. 112.

Steel has shown to greatest advantage when used in great masses; it depends upon its qualities as a mass rather than on its surface, where some measure of hardness has to be sacrificed to ensure the toughness through the mass. To those who judge only by the results of limited experiments it may probably appear that any attempt to get increased hardness in the face involves uncertainty in the quality of the mass. Apparently the tendency latterly has been to make steel sufficiently soft to ensure toughness, and consequently to admit of perforation when over-matched. *So long as all fire is kept out,* this may be right. Most Officers would prefer to admit the quantity of dead metal that would pass through such a plate as that fired at at Spezia in 1884 to the total demolition exhibited in the steel-faced plates on that occasion, dead metal still coming through, although in smaller fragments. Nevertheless, should projectiles improve in quality, the plates may have to be made harder. In the long run it seems probable that *hard* rather than *soft* armour will be preferred. Those who are not themselves engaged in manufacturing plates may probably wonder that compound armour, consisting of a hard steel face and tough steel foundation or body, has not before this been successfully made.[1]

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[1] The difference due to the compound plates being rolled, and the solid steel plates hammered, must not be lost sight of. It may naturally appear that rolling is less likely to reach the interior of a very thick plate than hammering with a 100-ton hammer. The very vibration of the latter, though a rough process, may tend to prevent crystallization and so to preserve fibrous structure, just as agitation of a matter in solution prevents the formation of large crystals. With this in view the author has looked for larger crystals in the interior of a rolled compound plate after fracture than near the exterior, but he cannot say that he found them hitherto.

PART II.

CHAPTER I.

GRUSON'S CHILLED-IRON ARMOUR.

THE introduction of chilled cast-iron has not been given in its historical order in the plate experiments, because it constitutes a distinct branch of investigation, and can be better dealt with as a separate subject. In two instances only has chilled-iron been fired at in the experiments dealt with, namely, once at Spezia in 1876, when its application was so unsuited to its character as not to deserve much notice, and once at Meppen in 1879, when a chilled-iron shield was made by Krupp, which Grüson repudiated, but which can hardly be said to have behaved badly (*vide* pp. 96–97, I.). Blocks of chilled-iron have been fired at at Shoeburyness, but in so imperfect a manner as not to deserve notice.

Herr Grüson claims to have invented chilled-iron shot,[1] the credit for which he disputes with the *late* Sir William Palliser. He designed chilled-iron armour, which has been advocated on the following grounds[2]:—Wrought-iron, he considers, resists on a bad principle. The material is soft and ductile, and its strength consists in its being held together by tenacity rather than in any direct power of resistance. Thus, a shot enters a soft material, and, as it enters, its passage is opposed by the difficulty of tearing the metal open. This form of resistance is objectionable on two grounds. In the first place it is local in its action, that is, the metal in the immediate spot has to bear the entire strain, and so perforation becomes feasible. It is true that from the same cause the injury effected is local also, and an advantage as to future powers of resistance may be claimed on that account for wrought-iron; but this does not affect the objection urged, namely, that the power to *keep out* the shot must be exerted by the metal in the immediate vicinity of the point of impact. The second objection urged is that the plate only resists in the action of destruction, and thus any shot that it has kept out has destroyed armour in the precise measure in which the armour has resisted it. A shot whose power falls far short of that necessary to penetrate the plate, expends all the work it has stored up in it in actually penetrating the plate to a corresponding extent; for it experienced no serious resistance on striking the surface, but was stopped gradually as it drove its way into the plate until it had performed all its quantum of work. This, it is urged, is a very unsatisfactory form of resistance, and it is claimed for chilled-iron that it resists the shot at its surface, that its surface does not sensibly yield at all, but transmits the shock into the mass of metal behind it and around it. In this way a blow must be sufficient to break the entire plate, or must fail to produce any appreciable effect. The mass of metal, it is urged, absorbs the blow in the same way in which an anvil stops the blows of a hammer. Consequently the plate is not sensibly injured by comparatively light blows. Then, again, any additional thickness in the armour strengthens chilled metal in a much greater degree than wrought-iron. To illustrate this, suppose Fig. 1, herewith, represents the method of yielding of a wrought-iron plate during the passage of a shot, a supposition which we know is approximately correct. And suppose Fig. 2 to represent the transmission of a shock through a chilled-iron plate sufficient to destroy it, a supposition which is fanciful, but which may be allowable for purposes of explanation. Then it may be seen that the portions of the plate which come into play and take part in the resistance may be represented by those shown in Figs. 3 and 4, by which it will be seen that if the portion of the wrought-iron plate *a* be supposed to be equivalent to the portion of chilled plate *d*, then equal additions to the thickness of

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[1] Development of Armour, Very, p. 532.

[2] Author's paper in *Engineer*, December 26, 1879, p. 465.

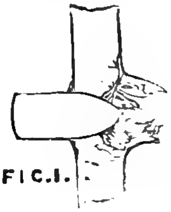
FIG. 1.

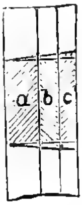

FIG. 3.

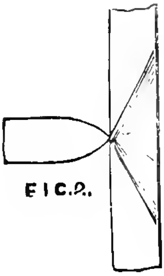
FIG. 2.

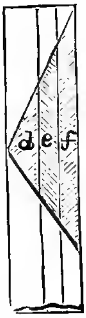

FIG. 4.

the two plates, as shown by *b* and *c*, and *e* and *f*, increase the strength of the chilled plate in much greater proportion than the wrought-iron one. Of course it will be urged in reply that though the work of a shot which fails to penetrate may not be visibly impressed on the plate, it may have been performed in another way on the particles of the metal so as to do its part towards eventual disintegration of the plate, without the visible effect so apparent in wrought-iron, and that the very distribution of the shock must tend to weaken all parts in the vicinity, and facilitate the action of a subsequent blow, whereas in wrought-iron the effect is so completely localized, that, as has been said, partial penetration practically leaves the plate uninjured. To pass on however to less questionable advantages offered by Grüson's armour. It admits of being cast in any desired shape, and with any desired variations in the thickness. Owing to the difficulty of rolling plates of any but the simplest form, wrought-iron turrets have nearly always been cylindrical with the metal of uniform thickness, and it is evident that the roof, at all events, may be much more suitably shaped on Grüson's system.[1] The curved form, together with the hard surface of the metal, enables this armour to throw off a shot striking obliquely. Then, again, chilled-iron plates may be easily cast in great masses; while in wrought-iron the difficulty of manufacture rapidly increases with the thickness and area. From this it follows that chilled plates may often be made near their destination if skilled men are sent there, chilled-iron armour is said for this and other reasons to be specially cheap. Lastly, but not least by any means, when suffering under the fire of Artillery capable of breaking it, there are no bolt heads, rivets, &c., to fly off as langridge into the interior of a turret, and any fragments of metal actually severed from the rest by cracks, generally remain held *in situ* for a considerable time, because the cracks are generally by no means straight, and because the arched form of the structure tends to favour their retention.

Briefly then it may be said that wrought-iron and chilled-iron represent soft and hard iron to the full extent. Wrought-iron resists and suffers locally, hence perforation is comparatively easy. Except in the immediate locality however the plate is little injured. Thus, seeing that it is generally impossible to strike the same spot twice, wrought-iron is singularly well suited for resisting long continued attacks from the fire of such guns as have not power to perforate it completely. On the other hand, it is more open to the passage of projectiles carrying fire into the interior than any other kind of armour. In all this, chilled-iron exhibits the very opposite qualities. It has the power to distribute the shock of impact through its mass. It probably never has been and never will be perforated. It yields by fracture and general disintegration. Long continued fire is what tries it most, and though the effect of the blows may appear to be slight, it cannot be doubted that the mass into which the shock is transmitted, suffers gradually, and the blows tell more and more as the firing proceeds, so in almost every detail wrought-iron and chilled present the opposite effects. Chilled-iron is well suited to throw off shot striking obliquely. In wrought-iron they have the best opportunity of biting. A blow enormously outmatching wrought-iron makes a clean hole, and effects the maximum possible of mischief behind the armour and the minimum on the armour itself. Such a blow will probably effect the minimum of injury on material protected by chilled-iron shields, while it will involve the armour itself in wholesale ruin. Lastly, wrought-iron lends itself to the work of strengthening shields by additional front plates, while finality is involved in the nature of a chilled-iron shield, to which it would be out of the question to make additions such as are contemplated in our own plate-upon-plate forts.

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[1] In the Schumann-Grüson Cupola, tried at Bucharest in 1885–86, steel-faced plates were pressed by hydraulic power into a curved shape, forming a dome.

Grüson's armour appears to have been first tried by Prussia at Tegel in 1868, and by Russia at Perm in 1871, with promising results,[1] and in 1873[2] such success was obtained as secured its adoption. Two 517 lb. shot were fired from an 11-inch (28^{cm}) Krupp gun, with an 88 lb. charge, at a plate whose maximum thickness was 28·3 inches, at 10 yards distance. Both shot struck the same place, and formed on the surface of the plate a rough spot a few millimetres in depth. Two slight cracks were observed commencing on the inside. The shot were broken to atoms. On July 27, 1874, another trial commenced. Captain Grenfell says[3] of this trial, which was completed on August 21, that the ten rounds fired against one plate left it far from unserviceable. Firing was then continued, and although the surface of the plate lost in appearance, no increase of damage, as far as the serviceability of the plate was concerned, could be discovered. Three things were remarked, (1) Throughout the whole of the practice no penetration into the plates was effected; the projectiles, were, in fact, effectually kept out. (2) Even after the plate was split in two parts, many shot were fired without producing any visible effect. (3) No injury beyond a crack occurred on the interior of the plate. Fig. 5, p. 5, II., exhibits the condition of the plate at the conclusion of the trial. The thickness of wrought-iron "*t*," that might have been perforated by a 517 lb. shot is about 14½ inches probably, the striking energy being given as 7027 foot-tons, which implies a striking velocity of about 1403 feet. The chilled-iron was about twice the thickness of the wrought-iron that might have been perforated then. It bore 19 rounds on a very confined area. At Tegel, in 1874, a turret with a shield, with a maximum thickness of 21·65 inches (55^{cm}) withstood 277 rounds from a 5·9-inch (15^{cm}) gun, twenty from a 7-inch (17^{cm}) gun, and two from an 11-inch (28^{cm}) gun. At this period, then, Grüson's metal shields deservedly established their reputation in Germany. The Prussian officers observed that while experiments had been going on with wrought-iron in England through long series of years, chilled-iron had been so far perfected as to be recommended in three or four years.

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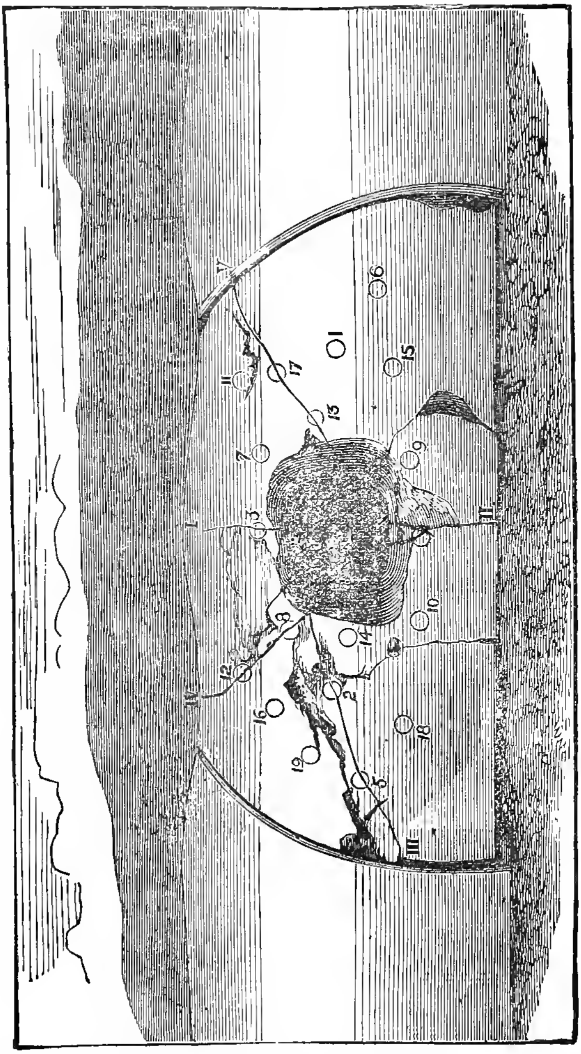
[1] See Development of Armour, by Very, pp. 533–534.

[2] *Engineer*, December 26, 1879, p. 466.

[3] Captain Grenfell, R.N., read an able paper on chilled-armour at the Institution of Naval Architects, in April, 1877, and advocated the trial of this armour in England. Major Küster, of the Prussian Artillery, reported the Tegel experiments in detail (*vide* Development of Armour, Very, p. 535).

Grüson's chilled iron shields in one or another form have been adopted by several powers. Germany adopted cupolas and batteries for coast and river defence, as, for example, those on the Lower Weser. Belgium has batteries which will be noticed later on.

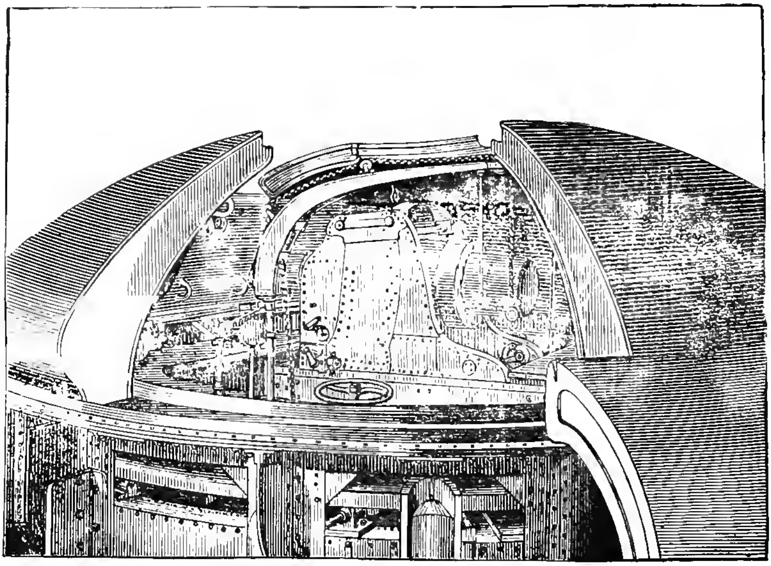
Fig. 5.



In Spain, turrets have been talked of for the defence of the Cadiz harbour, and in Portugal, for Lisbon and the mouth of the Tagus, but nothing has been actually done. Austria has also Grüson's armour. Italy ordered chilled-iron casemates for Alpine forts, and has recently adopted two chilled-iron turrets of great magnitude, each to contain two 119-ton Krupp guns for the defence of Spezia Harbour. France, for a time, adopted Grüson's armour for inland defences. This has subsequently been reversed,[1] and this class of shield in France, as in most other countries, is approved only for coasts. In 1882, it was found that while chilled-iron projectiles were broken up harmlessly against chilled-iron, this was not the case to the same extent with steel projectiles, whose tenacity enabled them to deliver more work at the point of impact, and produce much greater effect. Hence it was concluded that chilled-iron shields might be broken up under a long continued fire of steel projectiles, and on that account it was better suited to coast defence, where ships could not maintain a continued attack such as might be conducted in regular inland breaching operations.[2]

As has been seen, Grüson's armour offers a shield readily made, and very simple in its character, requiring no backing or supports, but itself forming the structure required. The iron employed should be of superior quality, free from phosphorus or sulphur, and of course of a selected mixture of grey and white, so as to combine the required hardness and toughness. The chilled part should not break suddenly to grey, as is sometimes seen in some superior brands of Swedish iron, but should shade off gradually. The cost is estimated at about £30 per ton. It is thought that the kind of metal required would be easily procured in most countries where iron fortifications are likely to be erected. Fig. 6, herewith, exhibits the general form taken by Grüson's

Fig. 6.



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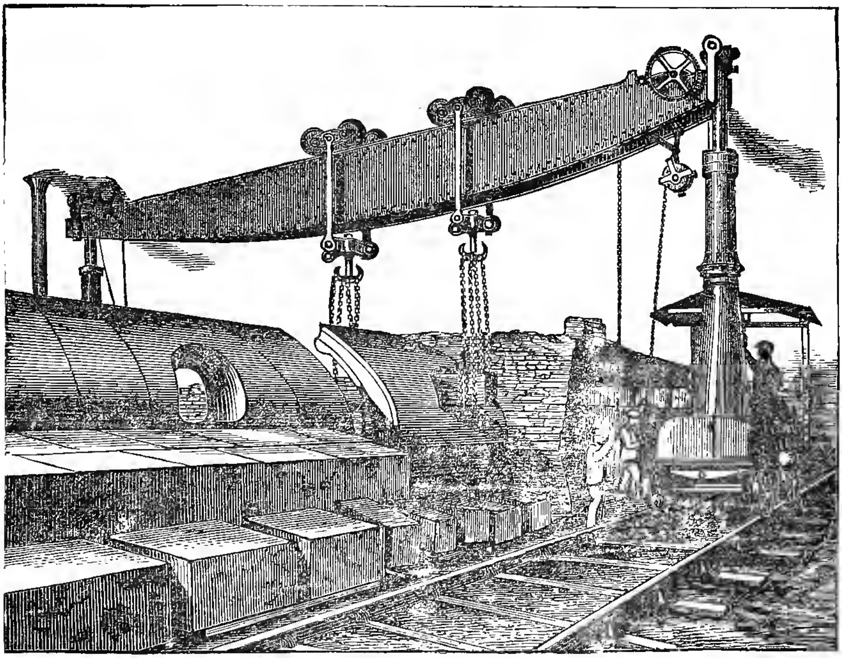
[1] This information the writer obtained incidentally when abroad, but it was verified for him by the kindness of the French Naval Attaché.

[2] *Vide* pp. 96-97, I., for Krupp's experiment on a chilled-iron shield made by him.

armour in a turret, or cupola as it is termed. The turret may be made to revolve by hand, the men working on the levers beneath. In some of the earlier examples central pivots were employed; but it is much better to dispense with them. The projectiles and cartridges are lifted from beneath, the guns being in all cases breech-loaders. It may be seen indeed that breech-loading guns are specially suited to this kind of armour. As with breech-loading, men are not required to stand upright at the muzzle of the gun, but only near the breech, the turret may be brought back in a gradual curve to the height required, so as to be dome-shaped, which saves metal, and adds[1] greatly to the strength of the structure, and to its power to throw off shot. Each turret generally contains two guns. Fig. 7, herewith, exhibits the structure of a battery in course of construction. The form of the battery is such as to give the armour the advantage of the curve of a cupola as far as practicable. It will be seen that the Grüson form of cupola and battery alike give a great advantage in strength of roof, which can be made strong enough to resist vertical fire. This is an important matter, inasmuch as chilled-armour, especially in the cupola form, is likely to be employed in those detached forts which play an important part in detaining an enemy, but which must eventually

Fig. 7.



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[1] The Author thinks that anyone looking at the St. Marie Battery on the right when ascending the Scheldt to Antwerp, will judge that it would be very difficult for a gun to make anything like a fair hit.

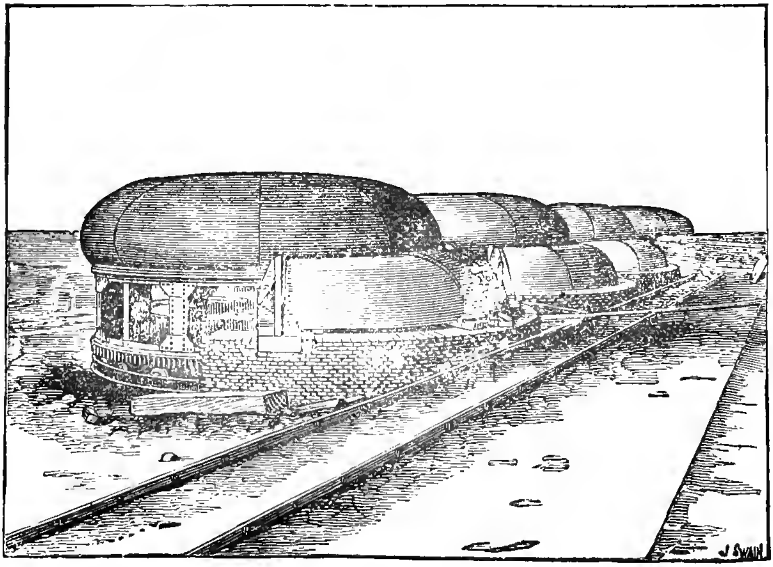
succumb to a regular attack, without being able, in most cases, to withdraw the armament or even the men.

Lieut.-Colonel Kromhout, of the Dutch Engineers, wrote a paper advocating the employment of cupolas for their "forts d'arret," as they are termed. He considers that two guns in cupolas may take the place of six guns in a fort, because it is rarely indeed that six guns directed in converging lines would be required to fire at the same time, and that two cupolas, by their power to revolve, could probably perform the same work, while they have the advantage of obtaining mutual cover. The saving of four pieces is not merely a matter of economy: it diminishes the prize that may eventually fall into the enemy's hands, not merely by the actual guns, but also the corresponding detachments and men and stores. Approaches, bridges, coast defences and the detached positions about Amsterdam, Colonel Kromhout thinks cupolas are specially suited to defend. He calculates that the roof might be made thick enough, not only to resist siege pieces hitherto employed for vertical fire, but also a special mortar of Krupp's of 8·27 ins. (21^{cm}) calibre, which fires a shell weighing 198 lbs., with a velocity of 1000 feet per second. Provision would be made for resisting such a projectile, even if its falling velocity were equal to its initial, by a roof of 5·9 ins. (15^{cm}) thick.

In Fig. 7, (p. 7, II.), the general character of the work may be seen. The segments are lifted by cranes, and lowered into their places, after which a mixture of zinc and lead, in all the earlier forts, has been run in between the joints. This fills up the recessed space seen on the ends of each portion, and gives the required solidity to the entire structure, supplying a method of union which is not liable to produce langridge.

Fig. 8 shows a line of cupolas erected for the Prussian Government,

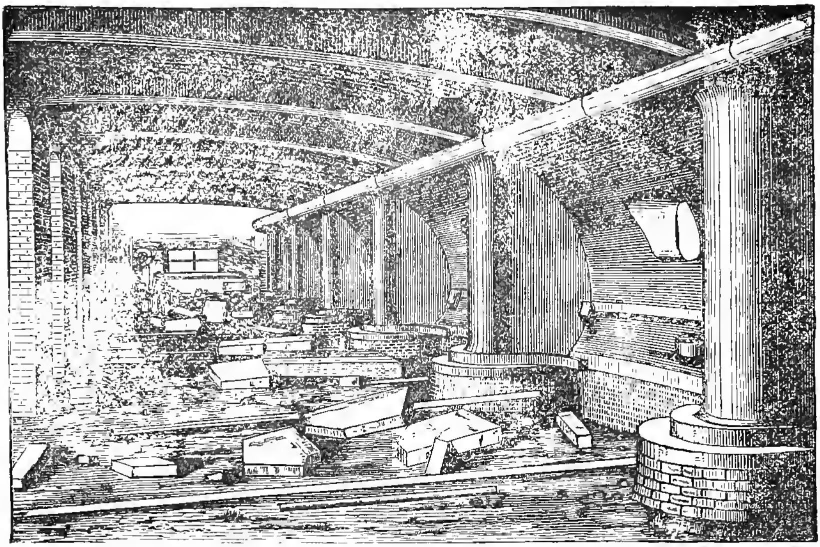
Fig. 8.



on the principal above referred to. In Germany, at the entrance of the river Weser near Bremerhafen, forts were erected with cupolas, one 6 and another 4, having one or two B. L. guns in each—also a Grüson battery with 9 guns.

Fig. 9 shows the interior of the St. Marie Battery erected for the defence of Antwerp. General Brialmont recommended the employment of chilled-iron at Malines as well as here. The armour of the St. Marie Battery has a maximum thickness at the port holes of 27·56 ins. (70^{cm}) and a minimum of 14·96 in. (38^{cm}) the covering varying from 13·78 to 7·87 ins. (35 to 20^{cm}) thick. The ammunition is stored under the casemate. The total weight of the structure is 800 tons. A port-hole plate weighs 35 tons, a pillar 25, and a covering plate 21·5 tons. These plates were sent to Antwerp by railway in special carriages. A revolving crane was used to put them on board ship which brought them by Scheldt to the fort. They were then carried and placed in position by means of rails and travelling and steam cranes.[1]

Fig. 9.



In some instances castings up to 50 tons weight have been employed. On the other hand, in the Italian Passes, it was stipulated that the maximum weight should be 13 tons.

An experiment was conducted on the[2] ground of Messrs. Grüson, at Buckau, on October 22nd, 1883, against a chilled-iron shield. The gun employed was a Krupp 30·5^{cm} (12 ins.) piece, 25 calibres long, mounted on a Grüson carriage. It fired a steel projectile of Krupp's, 3·5 calibres long, empty or blind, weighing 445 kilogs. (981 lbs.), the charge being 120 kilogs. (264½ lbs). The velocity was 445 metres (1460 ft.), and the striking energy or *vis viva* 4490 metre-tons (14,498 foot-tons). The shield consisted of five pieces of chilled iron forming half a tower—Fig. 1, p. 11, II. The rear or open part was supported by means of masonry piers to which it was connected—Fig. 1, p. 11, II. The entire weight of the shield was 47·5 tons. The first round struck a spot 4^{cm} to the right of the centre of the shield, and 90^{cm} from the bottom—Figs. 3 and 4, p. 11, II. The shot struck the plate in a normal direction at the point marked I on Fig. 4, forming a crack *a*. To the left of the point of impact a chipping off, or bruise. Round the point of impact a chipping or bruise of a maximum depth of 35^{mm}. The point of the shot itself was flattened out into a disc with a centre core which stuck to the shield. On the interior, the crack *a* was visible as a hair crack, running from a point 45^{cm} from the left edge to about 22^{cm} of the right edge, Fig. 2, p. 11, II., in which, however, the crack is shown as completed by subsequent firing. Other effects of a slight nature were visible.

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[1] Officers have obtained leave to see the St. Marie Battery by applying to their Nation Ministers at Brussels. The Author obtained permission in this way, but was prevented by an accident from seeing the interior of the battery.

[2] *Vide* original report of Grüson, *Engineer*, February 22, 1884, p. 141, also translation of original report by Captain W. H. Bixby, U. S. Engineers.

The second round was fired with a steel projectile weighing 446·3 kilogs. (983·9 lb.). It struck a point on the centre vertical line of the shield 100^{cm} over the first point of impact, II., in Figs. 3 and 4, p. 11, II., the axis of the shot having a striking angle of 51 degrees. A long curved crack *c* was found running up to within 50^{cm} of the top edge of the shield, and 17^{cm} of the left edge, Fig 4, also another crack *c* running to the right in a sharper curve nearly to the plate edge. A vertical crack *d* connected points of impact I. and II. together. It could not be traced beyond I. There were also four other hair cracks. A long chipping off also was made of 70^{mm} maximum depth, Fig. 4, p. 11, II.

In the interior, the crack *a* was completed and opened to a width of 1^{mm}. The cracks *c* and *d* were not visible in the interior. The horizontal plate was slightly moved back.

The third round had a projectile of 443·8 kilogs. (978·4 lb.) in weight. This struck a point, *see* III., Fig. 4, p. 11, II., 86^{cm} from shot I, and 90^{cm} from shot II. Striking angle, 72 degrees. Eight cracks were formed radiating from the point of impact, Fig. 4, one marked *e*, united III. and I.; another, *f*, ran parallel to *b* for a short distance. Crack *c* opened. The chipping-off or bruise at the point of impact was about 50^{mm} deep. Inside cracks connecting the *a* and *b* were developed in the manner shown in Fig. 2, below the point of impact III. A certain amount of general disturbance of parts also was effected.

The fourth round was with a shot weighing 444·6 kilogs. (980·2 lb.) The striking angle was about 75 degrees. The point of impact was 65^{cm} from the bottom edge and 84^{cm} from I (*vide* Fig. 4, p. 11, II.). This projectile, striking a fragment which was already detached from the rest of the shield, bodily moved it back, and to a certain extent dislodged and disarranged the entire structure.

FIG.1
NTIRE STRUCTURE
FIRED AT

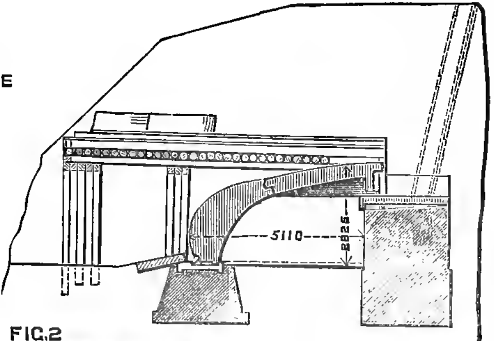
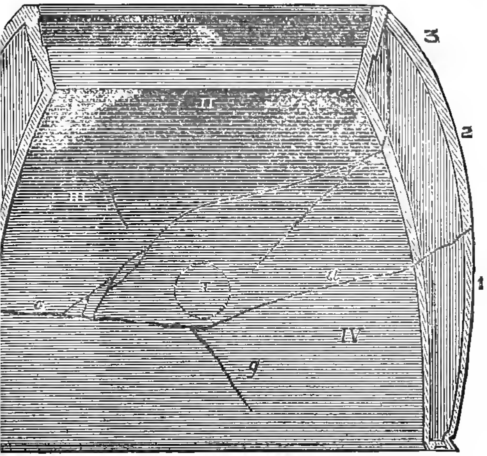


FIG.2



NTERIOR OF SHIELD SHOWING EFFECTS OF FIRE

FIG.3
SECTION OF SHIELD
SHOWING DIMENSIONS

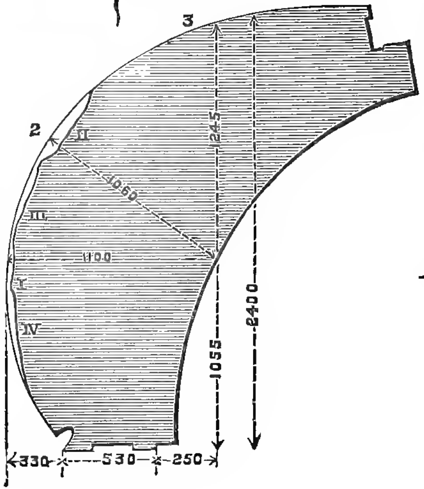
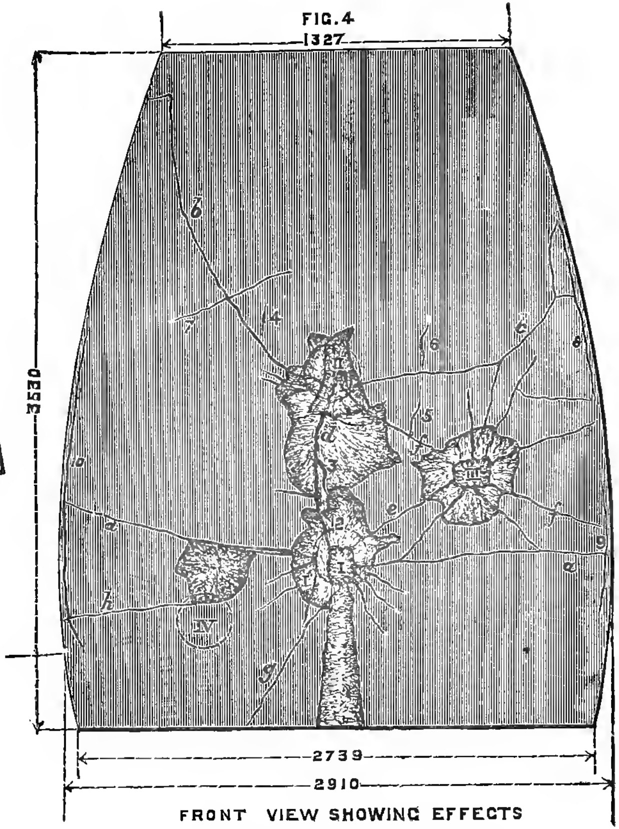


FIG.4



FRONT VIEW SHOWING EFFECTS

The shield received three blows, having a total *vis viva* or energy of 13,470 metre-tons (43,495 foot-tons), or 283·8 metre-tons (916 foot-tons) per ton of metal in the shield without the fragments of the shield being dislodged or the protection to the interior being lost. After the third round there were cracks extending entirely across the plate and through the whole thickness forming large fragments, but these fragments remained *in situ*; the wrinkles or lines formed in the surface of the cast in no way contributed to the formation of the cracks. The surface of the metal was chipped off round the points of impact, but in no case had any of the point of the shot entered more than 2·6 ins. (7^{cm}). After the fourth shot the pieces might still have held in their places had the supporting structure stood better; but as it was, the whole of the energy of the fourth shot was available for the removal of the detached fragment which it struck. In all instances, the steel projectiles broke up on impact.

On this experiment, Von Shütz, in an article in the *Neue Militärische Blätter,* observes that "evidently a cupola is not necessarily put out of action or prevented from revolving by the shattering of one of its plates." He considers that it is quite unnecessary to apologize for the fracture of the turret at the 4th blow; it had done its duty fully in resisting the first three blows. Nevertheless it ought to be pointed out that when erected for service, a revolving cupola is mounted on a strong wrought-iron frame, which, owing to its construction has considerable elasticity, and would absorb a considerable part of the shock of impact. At Buckau where no frame existed, the cracks opened and the plates moved in a way that can only be explained by this fact. Further the fact that a half cupola only was employed, deprived the structure of many of the advantages of its arched form. There was altogether, however, less spare resisting power than might have been supposed from the Tegel results. It might be objected that if the points of impact in this trial had been closer together a greater result might have been produced, but this is not supported by experience. Some Military authorities on the contrary hold that blows on points one or two calibres apart, which become connected by cracks, furnish the most effectual means of destroying chilled-iron. Von Shütz then remarks on the notable results obtained in perforating wrought-iron by Krupp's and others, declares compound plates to be no better,[1] and expresses a preference for chilled-iron shields, particularly on the ground of expense. He considers that while against Krupp's steel projectiles the resistance has not been so great as might have been expected from the Tegel trials, it is more than sufficient, and far superior to that of other systems. Moreover, the Buckau experiments have yielded important indications bearing on the perfecting of cupolas. The section of the first cupolas was designed to make the angle of impact as small as possible, but it turned out that chilled projectiles caused more havoc at oblique angles, hence the manufacturers made the profile less inclined, so as to increase the angle of impact. But that which was an advantage against chilled projectiles is the opposite when steel are used, and hence the profile must be now modified so as to resemble that of the early cupolas. In conclusion, Von Shütz pronounces iron necessary for coast defence, especially against heavy guns, and chilled-iron he considers the best description, observing that whatever changes in form may be necessary, chilled-iron lends itself to them without difficulty, and is reliable under all circumstances.

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[1] "Des experiences nombreuses ont démontré que les plaques-compound ne fournissent pas de meilleurs resultats."

Some experiments[1] were made on August 28th, 1884, against a shield 20 inches thick (52^{cm}) and about 14·66 tons weight, (14,900^{kg}), with a 5·9-in. (15^{cm}) gun firing a steel shell weighing 83·8 lbs. (38^{kg}), striking with 1114 foot-tons energy (345^{mt}), that is apparently with about 1385 feet velocity. The shield bore nine of such blows well.

A trial against a side plate of a turret of Grüson's chilled cast-iron, constructed for two 12^{cm} (4·7-in.) guns took place at Buckau, January 19th and 20th, 1885.

The object and programme of the experiment was to test the shield by twenty rounds of the Prussian 15^{cm} (5·9-in.) gun firing hardened steel shells (Ternitz) ; charge, 6·9 kilogs. (15·2 lb.) ; prismatic powder, "const. 68 ;" that is to give velocity equivalent to that at 1000 metres range (1094 yards). All the blows were delivered against the left half of the plate.

The plate was sought to be divided by the first five blows, rounds one to five, in two nearly equal parts, in order to attack the left half only, and in a way free from objects. Five projectiles out of the twenty to have flat heads. If the plate after fifteen blows, *i.e.*, ten per square metre of plate's vertical projection, should not be breached, and its interior surface not exhibit cracks dangerous to the gun detachments, the resistance should be considered sufficient. After this five more rounds should complete the experiment.

The form experimented on differs materially from that of previous shields, its construction being based on the results of former experiments. The profile is debased or flattened considerably, so as to avoid an angle of impact exceeding 46½ degrees, from a shell striking horizontally. The plate was fixed between two other side and one roof plate, so as to form nearly a half cupola. At the open side it was supported by pillars of masonry by means of intermediate iron coupling plates, the whole being protected from shell fire by earth and wood.

Fig. 1, p. 14, II., gives dimensions and profile of shield. The greatest width measuring round the curve—" développée "—was 3·8^{m} (12 ft. 1·7 in.) ; that at the top edge was 2·15^{m} (7 ft. 0·6-in.) The weight was 19,918 kilogs. (19 tons 12 cwt. 0 qrs. 7 lbs.) The Prussian 15^{cm} (5·9-in.) gun was mounted in position to deliver seven blows opposite to the centre of the plate at 36^{m} (118·1 ft.) range, for the remaining rounds at 24 degrees to the left. The projectiles employed were Ternitz hard tempered steel shells filled with sand and made up to 34·5 kilogs. (76·06 lb. weight). The charge was 6·9 kilogs. (15·2 lb.) prismatic powder as above stated. The initial velocity was 395^{m} (1296 ft.)

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[1] The author is indebted to Herr Grüson for kindly forwarding to him the printed reports on these 1883–84 trials, in reply to his request for information on them.

The first seven projectiles struck at angles of impact varying from 46 degs. 15 mins. to 25 degs. 56 mins. They all glanced and broke up. The hits are shown in Fig. 2, herewith, and Fig. 3, p. 15, II. Hair cracks were formed in the face of the shield, but nothing was visible at the back of the shield.

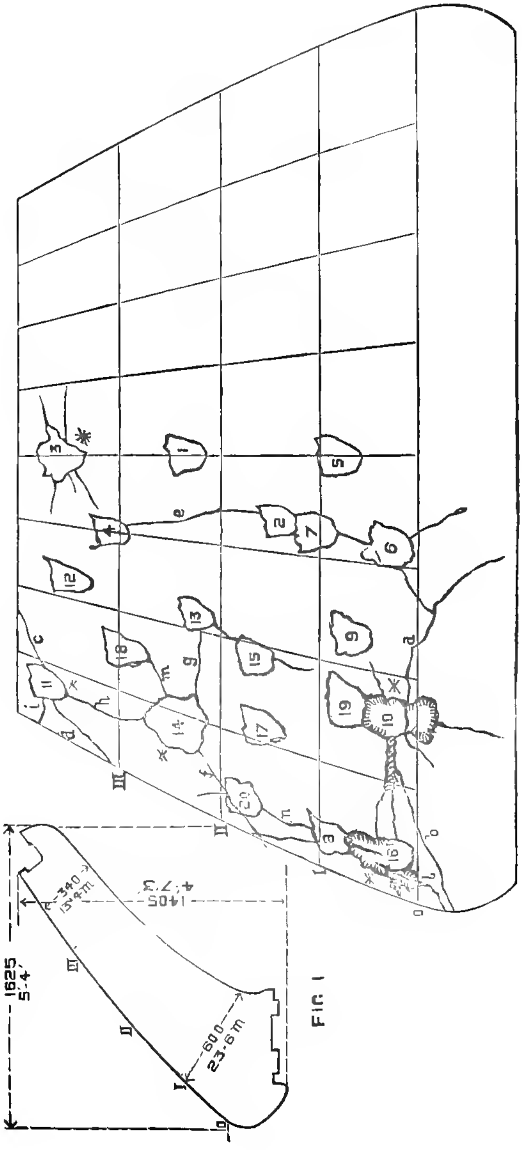
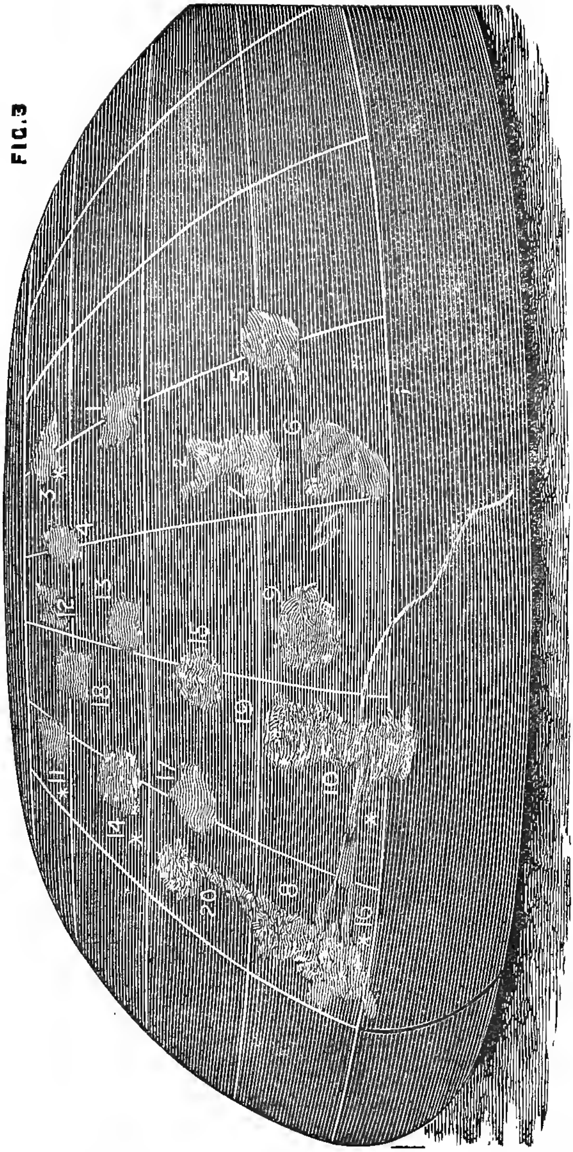


FIG. 2

FIG. 1

FIG. 3



On January 20th 1885,[1] the gun was fired from a point 24 degs. to the left of the original position, 36^{m} (118·1-ft.) range; that is, the lines from axis of shield to gun in the two positions apparently formed radii of a circle 24 degs. apart, so as to give lines of fire normal to the horizontal section of the shield. The next thirteen rounds struck at angles of impact from 46 degs. 28 mins. to 26 degs. 22 mins. All the projectiles broke up and all glanced except No. 16 round, which was a flat-headed projectile. Its head remained fixed in the plate. Rounds 3, 10, 11, 14 and 16 were flat or rather slightly concave-ended projectiles.

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[1] *Vide* article in *Engineer* based on reports obtained from Grüson, see *Engineer* of May 8, 1885.

The plate in all has borne 20 blows of steel shells, each 274·6 metre-tons (886·7 foot-tons) or 276 metre-tons (891 foot-tons) per ton of entire shield, or 552 metre-tons (1782 foot-tons) per ton of half shield attacked, or 1425·6 if the shield be reckoned up to the next white line, so as to include all the blows fairly, which certainly should be to obtain any idea of effect, without destroying its powers of resistance. The crack *d*, after the removal of the front shield, is perceived to extend under the surface without reaching the edge of the plate, so that the portion affected by it is not detached from the shield. The effect of the new flattened profile is shown to be very good, all the projectiles being thrown upwards. It is true that the flat-headed shells have had more effect than the others—their points of impact are marked on Fig. 2 with an asterisk * [1]—but they have not been able to destroy the plate. The shield has greatly exceeded the resisting power demanded of it, against the fifteen rounds. It is impossible to say, even approximately, the number of blows necessary to break the shield. The Ternitz steel shells equal the Krupp steel shells in tenacity and hardness. With a fractured point of the shell it is possible to scratch glass, just as with the Krupp steel. On the ground of this result some advocated the application of Grüson armour to inland forts and lines of defence.

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[1] If the depths of penetration of each projectile be divided by the sine of the angle of incidence, so as to bring them to the penetration which would be obtained in the normal or direct direction, that is, supposing they can for the moment be treated like penetrations into wrought-iron, the mean of the penetrations of the pointed projectiles is 0·459 inches, and that of the four flat-headed ones thus (excluding the one lodged) is 1·935 inches. The author sees all sorts of objections to this method of comparison, but it appears to be the only one available. The fact that the flat-headed shot obtained more than four times the penetration of the pointed ones, appears to be a more marked superiority than can be accounted for by accident.

CHAPTER II.

TRIAL OF GRUSON'S ARMOUR AT SPEZIA.

A TRIAL of Grüson's chilled armour, on a larger scale than had hitherto been attempted, was commenced at Spezia on Tuesday, April 20th, 1886. Before describing it, a few words of introduction may be desirable.

The Italian Government, having decided to erect two cupolas, each mounting two 119-ton Krupp guns, for the defence of Spezia, Herr Grüson was invited to construct them on his system, on the condition that he should make a test shield capable of bearing three blows from the projectile of the Armstrong 100-ton breech-loading gun, without any portion being detached from the interior. These blows were not to be within a metre of each other. A test shield was erected at Spezia, and it received its first blow on Tuesday, April 20th.

This experiment was as completely opposite in character to that made with the special Schumann-Grüson cupola at Bucharest as can well be conceived. The latter was the attack of armour by comparatively small siege guns, whose fire was continued day after day from a short distance, and accurately directed. In fact, it was the regular breaching of a siege battery calling for peculiar powers of endurance. Soft armour is specially suited to resist a regular breaching attack, and both the structures tested at Bucharest were composed of soft wrought-iron, although one had a hard steel face.[1] That trial was specially valuable to England, as being a test of the two kinds of armour adopted by us. It was, therefore, instructive with regard to our powers of defence.

The exact opposite of all this may be said of this Spezia-Grüson trial. Coast forts must expect to be attacked by the heaviest guns existing, but it may reasonably be hoped that very few blows will be actually delivered on their sides, for there is no likelihood of a ship being able to remain opposite a fort many hours, much less day after day. The ship's fire will consequently neither have the accuracy of siege fire, which is due to a short range and a fixed position, nor will it be very long sustained. The power to resist a few heavy blows is therefore what is called for. This power Grüson's armour of chilled-iron admirably supplies. It forms the hardest shield possible. The metal transmitting the shock through its mass, it is impossible to injure anything covered by it, until the shield is broken and displaced. A blow greatly outmatching the resisting power of the shield may cause wholesale fracture, and leave a battery much more exposed to future fire than would be the case with soft armour, which, under such conditions, would let the projectile through it. In the case of Grüson's armour the blow performs the maximum work on the shield, and the minimum on the battery behind it, and in the case of soft armour a shot performs the minimum of work on the shield and the maximum on the battery behind it. Consequently, it may be seen, without further comparison, that Grüson's shield is well suited to resist a few heavy blows, and is therefore well adapted to coast defence. It may generally be assumed that so long as a Gruson's shield stands up in front of a gun, that gun is safe against the next blow, even should that blow greatly out-match the shield. And the safety of the detachment is secured in a peculiar degree by the fact that there are no bolt-heads to fly off, and no langridge until the shield is broken up. The experiment should be peculiarly interesting to the British Government, as regards offensive operations. Seeing that foreign coast armoured forts are made almost without exception of chilled-iron, it follows that our ships can never engage land shields of any other kind. The attack of armoured coast forts is no doubt a serious operation, and is only justified by strong reasons; but surely such a possibility must be contemplated, or why should coast forts be built? Certainly nothing but ships can attack them.

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[1] This trial was witnessed by the author at Spezia, and reported in *Engineer* of April 30, May 7, and May 14, 1886.

It might appear, perhaps, that enough has been said to show the importance of the trial at Spezia, but the special reason, as concerns England, yet remains. English compound armour, in spite of its hard skin, does not call for the same qualities in a projectile that appear to be needed for the best attacks of chilled-iron. As before pointed out, our chilled-iron service shot, which are of their kind excellent, have exhibited such powers against steel-faced plates, that there is considerable danger of overlooking the fact that such projectiles are probably almost useless against chilled-iron. Certainly no foreign chilled-iron shot has been found to be of much avail against it. The shot meets with an abrupt shock directly its point touches the shield. The best steel flies into pieces, but in the act of doing so, its tenacity is sufficient to enable it to deliver a great shock on the shield. A chilled-iron shot has little tenacity, and it is caught at a disadvantage when resisted without the chance of getting its point any sensible distance into the plate. Hence it breaks up without delivering a blow at all proportionate to its energy. A blow that comes after fracture of shot in the form of a mass of fragments, is, of course, of no use against armour. Consequently, as before noticed, chilled-iron armour, when tested in France by chilled shot only, was approved for inland defences, but when afterwards it was attacked by steel projectiles in 1882, its use was restricted to coast defence. Grüson then, as already seen, altered the profile of his shields, the better to meet the attack of steel projectiles; and the test of the shield which, with ordinary steel projectiles is formidable, became much more so now, because, since the time when the terms were accepted by Grüson, great improvements had been effected in the manufacture of steel projectiles by Krupp, and consequently those now supplied by him for this purpose were peculiarly formidable.

The Armstrong 100-ton B. L. gun is probably about as powerful as the Krupp 119-ton gun. This should be borne in mind, because, while many are aware that the Armstrong 110-ton gun—*i.e.*, the *Benbow* gun—is by far the most powerful gun in the world, probably few would expect that the 100-ton B. L. gun, made as long ago as 1882, would be as powerful as Krupp's 119-ton gun, a piece which, in April, 1886, was not yet delivered in Italy, and could only be judged of by data furnished to the above effect.

Herr Grüson's shield is shown in Figs. 1, 2, and 11, p. 24, II., which

FIG. 1

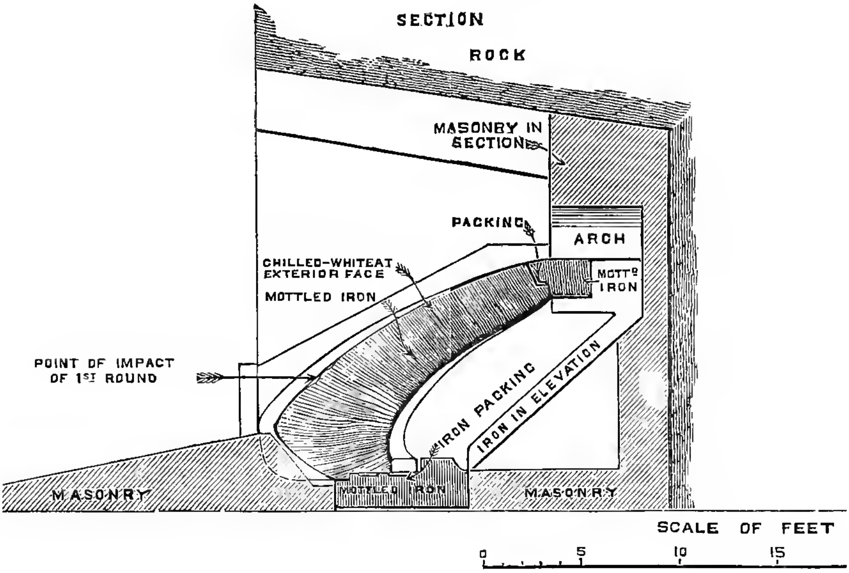
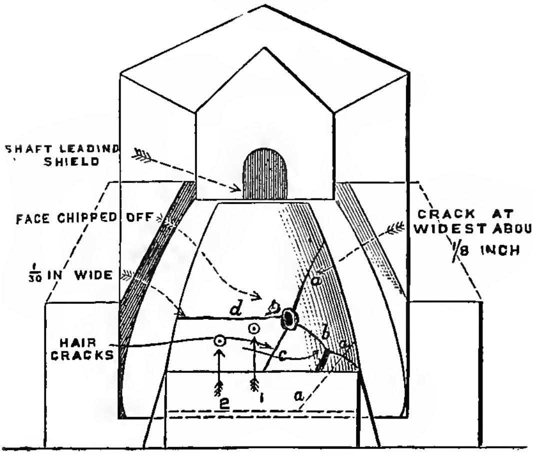

SECTION

FIG. 2
FRONT ELEVATION



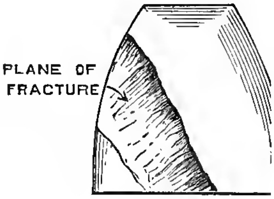


FIG. 4

exhibit it in section, front elevation, and plan. The chilled portion, which forms the main portion and receives the blow, weighs about 87,950 kg., or 86·56 tons, and is of the shape shown in Fig. 7, p. 22, II. In the complete turret there are to be twelve plates similar to this, and three broken by the two gun ports. The interior diameter of the cupola is to be about 10 metres. The shield is chilled white on its exterior face. The interior and other pieces of iron are mottled. The trial plate is fixed between two cheeks of iron, which are made large enough to obtain a good bearing on the masonry at each side, and thus to put the shield in as nearly the same condition as possible as that in which it would be placed in an actual turret. The recesses at the end of the plate are now made to fit, white metal not being necessary to key them together.

The firing took place in St. Maria Bay, in the Gulf of Spezia, where the shield was erected facing the sea. This shield being intended for a land fort, the experiment was conducted by General Giovanetti, and the Commission appointed for this branch of the work. The gun itself was in the hands of the Navy.

The projectile was intended to strike the shield in the same way as it would if the path of the shot were inclined downwards at an angle of 1°, and the shield standing on a horizontal base. For this purpose, as the gun fired slightly upwards, the shield was, as it were, tilted very slightly forwards; that is to say, forward to the extent of 1½ deg. in comparison to its position set on a truly horizontal base, 1 deg. for the supposed descending angle, and ½ deg for the difference in level of shield and gun. From what has been said as to the construction of the complete turret, it may be seen that the chilled plate, actually receiving the blows, was the only part of the target which corresponded to the turret. All other parts were substitutes. For example, the two large iron side pieces served to give a bearing on the masonry nearly corresponding to the support which would be afforded by the contiguous portions of the turret, which should be smaller in area but more rigid than masonry of the same extent. The mottled iron piece at the top of the shield did duty for the circular crown of the turret, while the mottled piece at the base took the place of the plate forming the base of the turret. Even the small wrought-iron packing plates in the joints are substitutes for the filling in of the joint by white metal or by keys fitting to the front plate. Lastly, the masonry glacis took the place of the glacis with chilled-iron "vorpanzer," shown in the approximate cross section of the complete cupola, Fig. 12, p. 33, II., which, like the plan, Fig. 12, p. 33, II., is drawn from description, not copied from any drawing, and is therefore only approximate.

The first round was aimed at a point marked by ⟶ 1, Fig. 2, p. 19, II. The gun, as in previous Spezia trials, was fired from a raft on the sea. It was therefore subject to a little movement, and the shot actually struck at the point of impact shown by the bruise, with cracks radiating from it, in Fig. 2, p. 19, II., and by the arrow in Fig. 1, p. 19, II. The projectile broke into small fragments, which were thrown upwards. The angle of incidence was 40 degs. The point did not hold, and a shallow scoop was formed with front cracks radiating as shown in Fig.

2, p. 19, II., by the letters *a, b, c, d.* Crack *a* was perhaps $\frac{1}{8}$-inch wide near the point of impact; crack *d* was considerably narrower; and *b* and *c* were hair cracks. Inside the shield is seen a fine crack running along opposite to the dotted line shown *a a* in Fig. 2, p. 19, II.—that is, across one foot of the shield shown in Fig. 4, p. 19, II., which exhibits the portion of the plate which may be separated from the rest of the shield if the front cracks *a* and *c*, and the rear cracks *a a* are one and the same. Whether this was the case or not, the shield bore the blow very well, considering the magnitude of it, and the character of the projectile. The striking energy was 47,499 foot-tons; the weight of the projectile was 1000 kg. or 2204·6 lbs. (nearly a ton); the striking velocity was 537·2 metres (1762·5 feet); the calculated perforation through wrought-iron was 31·2 inches; the energy per ton of shield was 548·9 tons; the charge, 375 kilogs., or 826·7 lbs., Cologne prismatic cocoa powder; the range was about 133·7 metres (438·7 feet). On service such a blow as this could scarcely be given, the range being specially short. On Saturday, April 24th, the firing was continued. The gun on its raft was again brought into position at a range from the shield of 133·7 metres, or 438·7 ft.

On April 24th, the gun was fired under conditions as exactly similar to those existing on April 20th as possible. The striking velocity taken was 537·9 metres (1764·8 ft.) the striking energy being 14,747 metre-tons (47,529 foot-tons). The perforation through iron would be 31·2 ins. This does not apply to a hard target which cannot be perforated but must be broken. The blow, estimated on the principle of shock in proportion to mass of shield, is 550·7 foot-tons per ton of shield. The projectile was as before, a Krupp steel hollow projectile forged and hardened. The form and dimensions are shown in Figs. 13 and 14, p. 23, II. Tool marks were visible from base to point. The projectile had, of course, been hardened subsequently to being tooled. There was a screw base plug somewhat resembling our own. The pressure in the gun was not taken. The projectile of the second round struck a few inches to the right, and high of the point aimed at—that is, it struck rather nearer to the point of impact of the first round than was intended, with an angle of incidence of 44 degs. As on the last occasion, the projectile was nearly entirely broken up into small fragments. One piece, however, of about 56 lbs. weight was found; it had formed part of the base end. It is shown in Fig. 15, p. 23, II. The quality of the steel appeared to be excellent. It was pretty hard throughout, though some metal in a softer condition than the rest was said to have been found about the centre.

Fig. 16, p. 23, II., shows the section of the shield.

The effect on the shield is shown in Fig. 8, p. 23, II. As will be seen the shot made a more serious indentation than before, the depth of it being about 4 ins., while that of round 1 was only 2 ins. Several cracks were made and opened in the plate (see 2, Fig. 8). Some cracks, marked A, B, C, D, were opened as wide as 1½ ins., and in some places the surface of the metal was chipped off. The wide cracks being low down, and cracks generally extending downwards, it is quite possible that these may come out at the bottom surface of the shield, so that they cannot be seen at the back. One iron side-piece was broken through. Fig. 8, p. 23, II., shows the position of the cracks in back ε, γ, and δ, and a small chip off at B. These are all near the bottom, but it may be seen, if their course be considered (*vide* dotted lines in Fig. 8, shown as if the plate were transparent) that it is probable that ε and δ at back corresponding with *d k* and *g* in the front. If α at back corresponds with *a* and *c* in front, it follows that the junction of γ and α may be identified with point of impact 1, and of ε and δ with 2. One iron side piece was cracked, as shown in

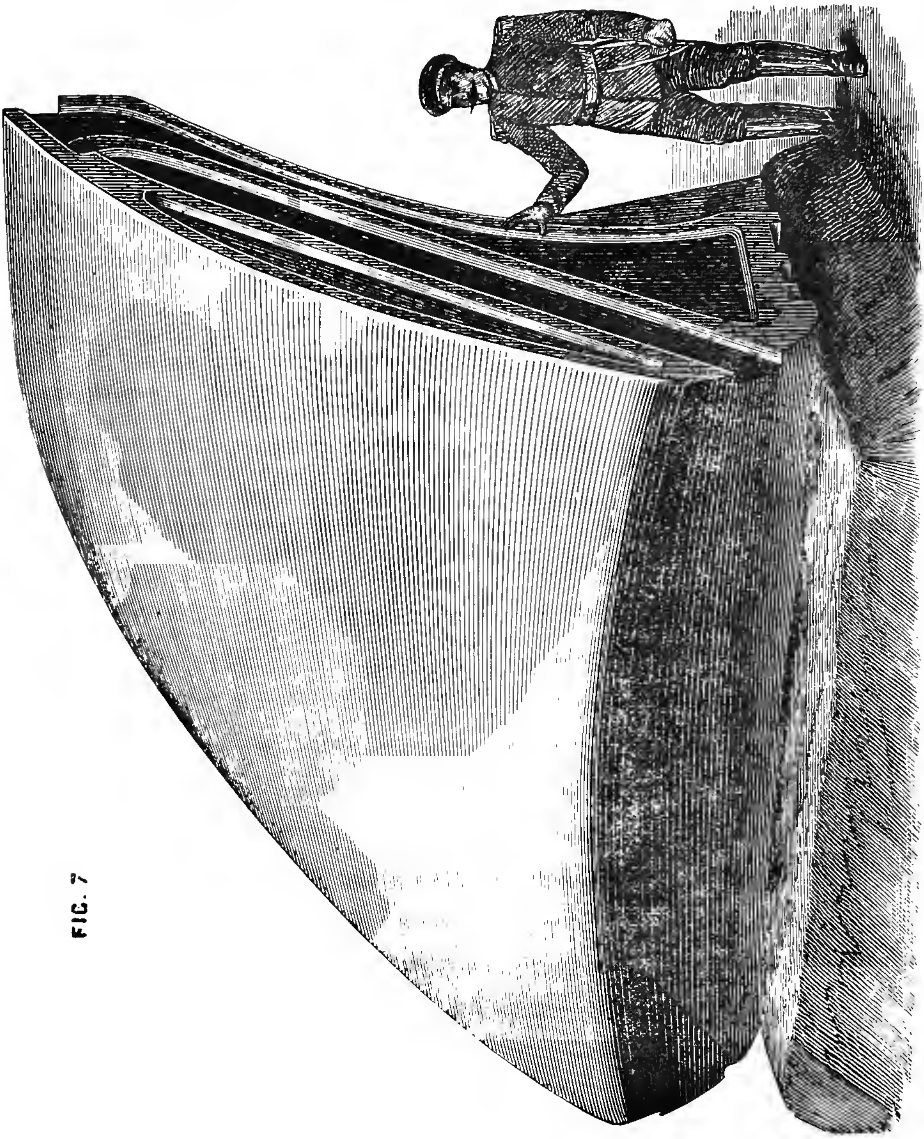
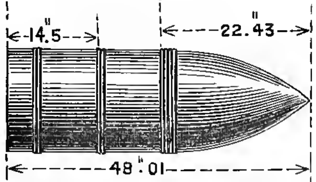


FIG. 7

FIG. 13.



KRUPP-STEEL-PROJECTILE
-FORCED-

FIG. 14.

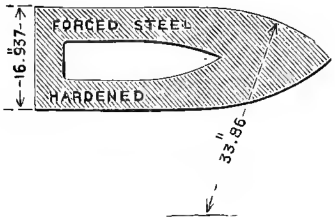
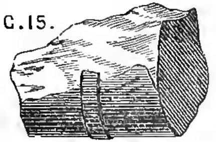


FIG. 15.



LARGEST FRAGMENT
ABOUT 56 LBS WEIGHT

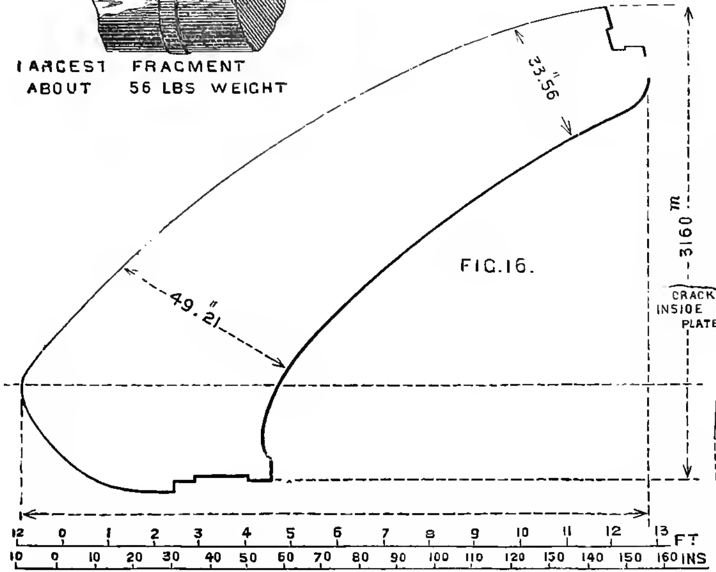
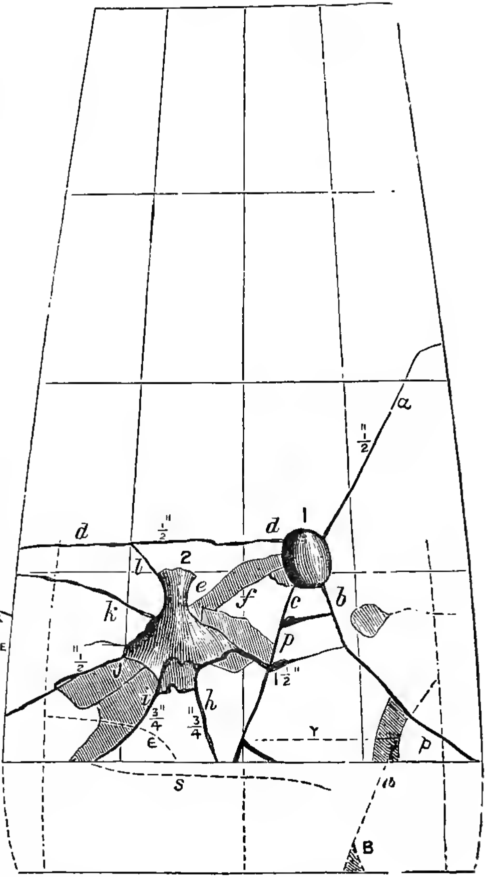


FIG. 16.
33.56"
49.21"
3160 m
12 0 1 2 3 4 5 6 7 8 9 10 11 12 13 FT
10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 INS

FIG. 8.



FRONT OF SHIELD DEVELOPED

FIG. 11

HORIZONTAL SECTION THROUGH A. B.

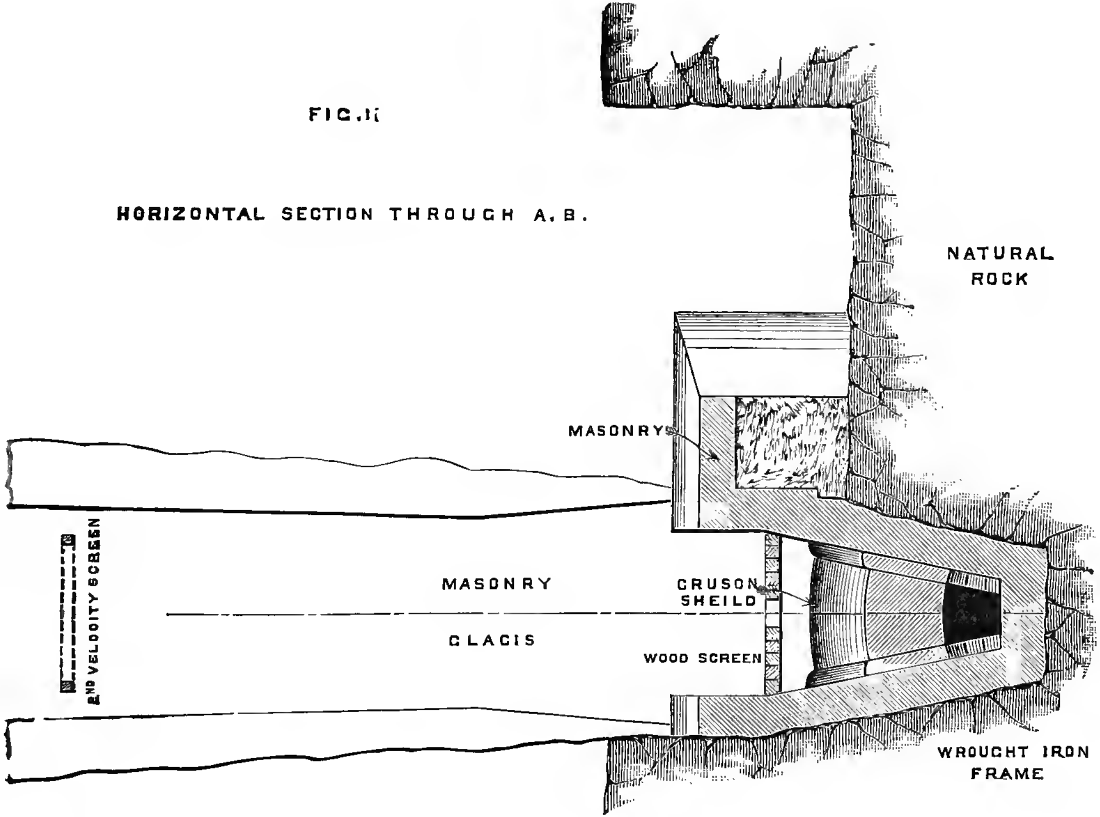


FIG. 9

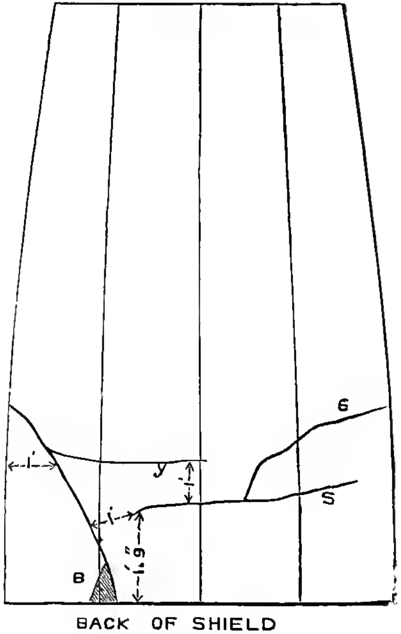


Fig. 8, and the supporting masonry was a very little shaken, so that a little space is opened behind the bearings of the shield. The plate had now received a considerable shock. It must, however, be considered to have stood admirably. No shield had ever yet received two such blows as this. The weight of the shield is, of course, great, so that the striking energy per ton is not very large. It must, however, be remembered that, owing to the excellence of the steel, a much larger proportion of the striking energy of projectile is impressed on the plate than usual.

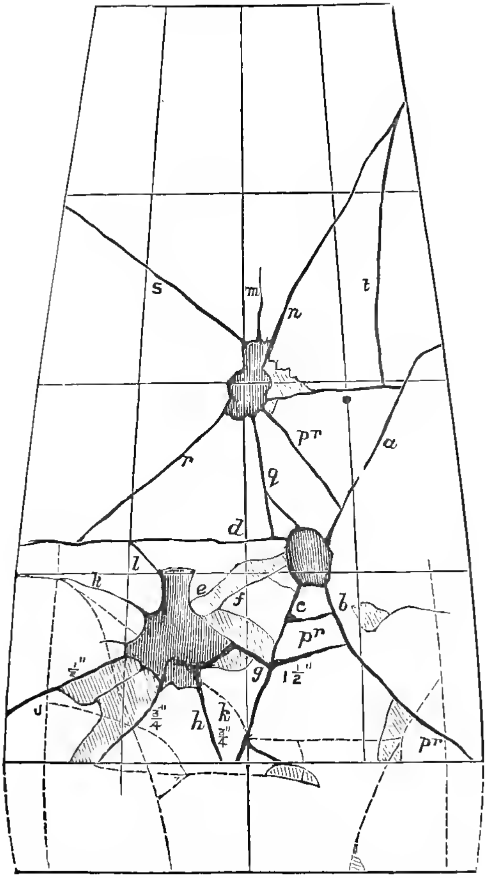
The cracks at the back were of course the beginning of the splitting up of the shield. Up to the present time anyone might have remained inside the shield in complete safety, because there is no langridge of any kind, the absence of bolts being a great advantage. It has been mentioned as a condition that no portion should be detached on the inside. It may be urged that this was done now for a small scale close to the ground at B, Fig. 9, was detached. On the other hand, the actual impressions of the projectiles points were less than a metre apart. Practically neither of these conditions were broken.

A third round was fired at the Grüson shield on Thursday, April 29th, from the Elswick 100-ton breech-loading gun, the firing conditions being as nearly possible the same as in the two previous rounds. The third Krupp forged steel projectile was employed, its weight being made up to 1000 kg., or 2204·6 lbs. The charge was again 375 kg. (826·7 lbs.) of Cologne prismatic powder; the striking velocity was 536·1 metres, or 1758·9 ft. per second. The striking energy being therefore 14,651 metre-tons, or 47,306 foot-tons. Pressures in the bore were registered as 2010, 1973, 1985, and 2025 atmospheres, the mean being 1998 atmospheres, or 13·11 tons per square inch. The charge in each round was made up in four cartridges ribbed longitudinally with serge rolls so as to make the charge lie in the bore with a space round it. The crusher gauges, tubes, and obturator, were, of course, as employed at Elswick.

After the second round, as already noticed, owing it is said to the impossibility of masonry and cement supporting the iron shield as well as the contiguous iron plates of a cupola or iron fort, a slight space had opened behind the edge of the plate on either side. In fact there had been sufficient yielding to cause a little anxiety as to the conditions under which the shield would receive the third shot.

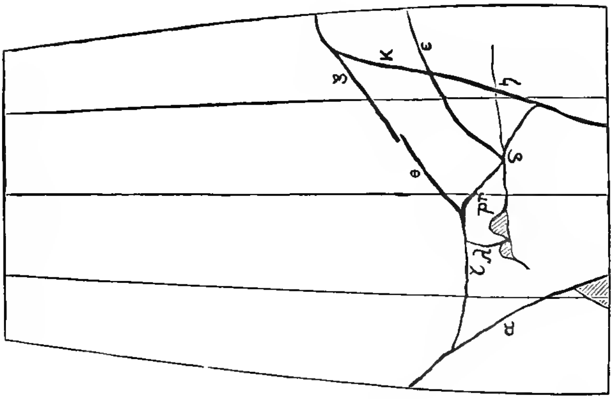
This was delivered on a spot close to the centre line running down the shield and about a metre from Round 1, see Fig. 17, p. 26, II., on which the cracks are shown in the front of the shield by continuous lines, and on the back in dotted lines seen through as if the shield were transparent. The angle of incidence being more oblique than before, the indent of the projectile was less, being about 1½ inch. The projectile flew into smaller pieces than before apparently, but the blow was sufficient to crack the shield, which is much thinner here, in lines shown in Fig. 17, p. 26, II., as *m*, *n*, *o*, *p*, *q*, *r*, *s* and *t*, as well as a small crack connecting *q* with point of impact 1. The portion of plate between *t* and the edge was entirely separated from the rest of the shield, so that it could be removed. It extended to the depth of about

FIG. 17



FRONT OF SHIELD
DEVELOPED

FIG 18



a foot at the plate edge, but rapidly curved up to the surface at *t*. In spite of this cracking and splitting, however, the shield appeared not only to be in condition to receive another blow, but Herr Grüson thought its position improved, inasmuch as it had so sprung as to close the opening visible at the last round, and was therefore now better supported. In the inside cracks η, κ, ζ, θ, and λ, (see Fig. 18, p. 26, II.) were formed, and two very small pieces were detached near λ, (*vide* Fig. 18), where the plate had obviously felt the blow severely, the fragment in the centre marked *p r* projecting slightly, and the cracks there being deep and opened. The following table gives the details as to velocity and energy of each round more exactly and fully than we have hitherto stated them :—

Ballistic Power of 100-ton Breech-Loading Armstrong Gun Fired at Spezia on April 20th, 24th, and 29th, 1886.

	Number of round.		
	First.	Second.	Third.
Velocity at muzzle, in metres	541·2	541·9	540·1
〃 〃 feet	1775·6	1777·9	1772·0
〃 85 metres, in metres	538·6	539·3	537·5
〃 278·9 feet, in feet	1767·1	1769·4	1763·5
〃 striking, in metres	537·2	537·9	536·1
〃 〃 feet	1762·5	1764·8	1758·9
Energy at muzzle, metre-tons	14,929	14,966	14,871
〃 〃 foot-tons	48,207	48,326	48,019
〃 striking in metre-tons	14,709	14,747	14,651
〃 〃 foot-tons	47,499	47,629	47,306
〃 〃 per inch circumference ... ... foot-tons	892·8	896·9	888·6
Perforation in wrought-iron at striking ... ... inches	31·2	31·2	31·1
Angle of incidence of projectile with tangent to shield ...	40 degs.	44 degs.	34½ degs.
Energy in foot-tons at impact per ton of shield	548·9	550·1	546·4

On the whole the shield had acquitted itself admirably, for it had borne the three blows without any fragment of any importance being dislodged in the inside. The small pieces, from parts shown shaded, which came off, appear to have been shaken and dropped down rather than flown out, and a detachment of men behind this shield would have remained uninjured. Bolt heads generally fly with violence, because their fracture is due to a strain of the bolt, which causes them to spring into the interior. This does not seem to be the case with pieces that may be dislodged by cracking. At all events it must be admitted that the defensive power of a shield which resists three blows of the projectile of the most powerful gun in existence is remarkable.

We may add that such a judgment was expressed by the Commission, that Herr Grüson was able to telegraph in the afternoon to push forward the manufacture of the plates required for the two cupolas.

The question was raised, as it was inevitable should be the case, as to the excellence of the Krupp projectiles which had thus broken on the shield. One or two queer looking bits were found, and persons stated that they found pieces that proved rather soft under the file. There was however nothing tangible to shake belief in the projectiles being excellent ones. At all events, nothing could be a fairer proposal than that which was made by Krupp's agent, M. Otto Budde. A competitive trial of steel 15^{cm} projectile had been carried on at Muggiana, Spezia. In this Krupp's had proved themselves the best. Shells of 15^{cm} had been fired point blank at very thick steel plates—about 18 ins. thick. These entered to a depth of about 1½ calibres, and rebounded without alteration of form, so that they could be again fired. M. Budde suggested that these projectiles, whose quality had been thus proved to be extraordinary, should be fired at the Grüson shield, against which, striking obliquely as they must do, he stated that they would break up exactly in the same way as the large projectiles.

There was a wish expressed to see a French St. Chamond steel projectile fired against the shield. These are excellent, but they were said to be softer than Krupp's, and the question arises as to what are the qualities that are most needed in short to enable them to act well against chilled-iron armour. On this matter we have literally no experience in England. Krupp's belief appears to be that the blow delivered by the shot depends on its limit of elasticity. Not that the projectile has the opportunity of recovering its form when the strain falls within this limit, but rather probably because no sensible change of form really takes place within it, and because directly deformation commences, the resistance of the shot decreases so rapidly that little more work can be got out of it. It appears probable however that the ultimate tenacity, as well as the limit of elasticity, would be the measure of the shot's power in this case of oblique impact. In direct impact undoubtedly, on deformation commencing, all penetration comes quickly to an end, but where no penetration in the ordinary sense can be effected, surely as long as the projectile holds together, so long it impresses its energy on the shield at the point of impact. As deformation commences, its power rapidly declines, but still, after commencing an injury, any following up of the blow at the exact spot acts in so telling a way that it may well be supposed that between the limit of elasticity and that of ultimate tenacity a sensible amount of work existed, and that the latter limit, as well as the former, should be considered. Indeed, slight deformation may not destroy all perforating power. In the competitive shot trials (see pp. 74–77, I.), Whitworth's projectiles, after being slightly set up, perforated plates which proved more than a match for most shot.

With regard to St. Chamond projectiles and other French steel ones, little is known out of France, but it is stated that at Gâvres great results have been obtained. It is expected that steel projectiles should perforate steel plates about a calibre and a quarter thick without deformation. In this country it is commonly stated that French steel plates are being made soft. This appears to be true in a measure; nevertheless, the French compound plates, whose powers we know are not very different from our own made on the same patent, are perforated more easily than the French steel plates. After such proof of the excellence of Krupp's steel projectiles, a good deal of evidence is needed to make us accept the statement that the French were as good, or better; but it may be so. One thing was unfortunately quite clear, namely, that England at this time had dropped far behind in the matter of steel projectiles, and it may be feared that until really hard armour should be tried in this country too much confidence may continue to be placed in our chilled-iron shells. These are, of their

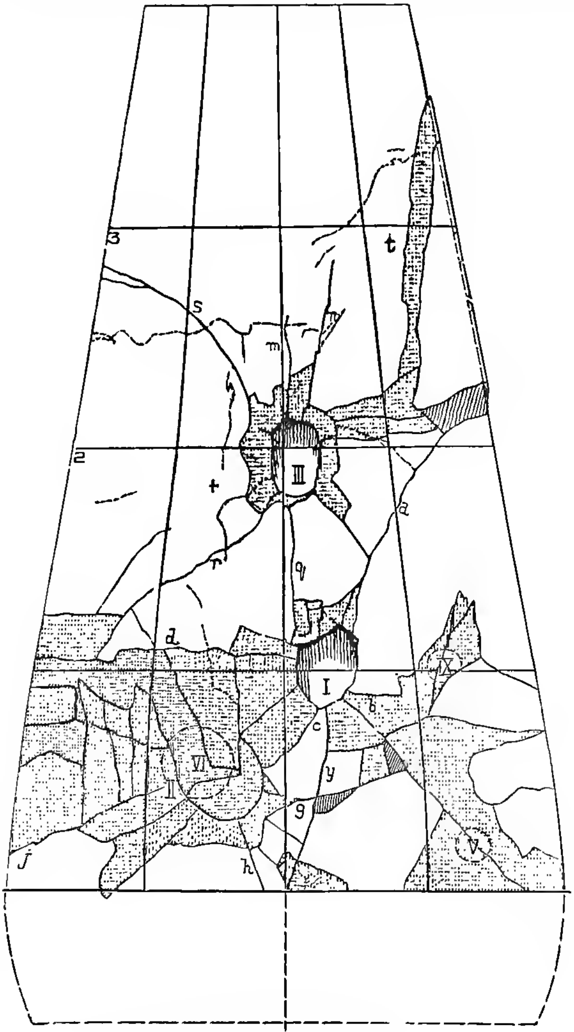


FIG. I
DEVELOPMENT OF SURFACE

sort, excellent, possibly the best in the world; but in France, Germany, and Italy, it has been found absolutely useless to fire any chilled projectiles at really hard armour. Surely it would be mad to expect that our chilled shot would be of much use against a Grüson shield unless we prove this to be the case by actual trial. A Grüson shield erected at Shoeburyness would teach us much as to our neighbours' armour, and as to our projectiles. A shield is surely worth trying for its own sake, which, so long as it holds together, offers complete security to the battery behind it, and which can be made to keep out three projectiles, any one of which would have gone clean through

FIG. 2

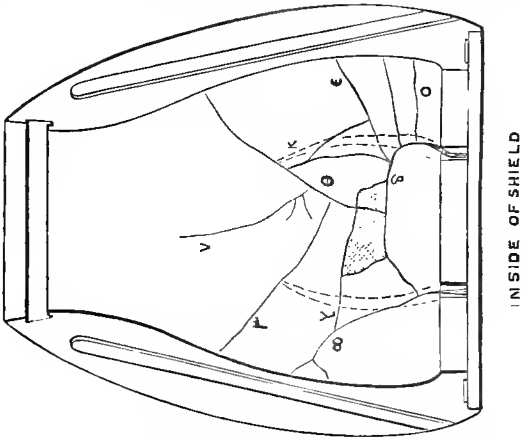
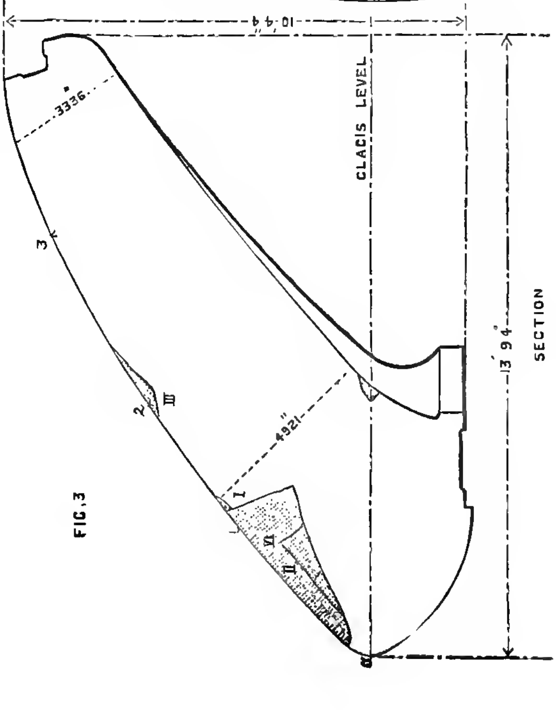


FIG. 3



almost any armour we possess either on ships or forts. It is still more important to try it for the sake of the knowledge it affords us of the power of our own projectiles against foreign armour. It can hardly be doubted by any one that we are far behind in the matter of projectiles. French steel shot go through at least a calibre and a quarter thickness of steel without deformation, and Krupp projectiles enter a calibre and a half into steel armour of thickness totally disproportionate to the shot, and bound back apparently undeformed and uninjured.

On July 9th, 1886, a programme was drawn up to carry out the suggestions made with a view of testing the excellence of the Krupp projectiles which had been used in the trial, and consequently establishing the estimate which had been formed of the resisting power of the shield which had been subjected to the three blows from these projectiles. The structure had been patched up, the masonry having yielded slightly as well as the shield. The cracks in the latter were opened with steel wedges, and filled up by running in zinc.

The first firing consisted in two rounds from a 15^{cm} (3·9-in.) Armstrong gun, 28 calibres long, on an Albini carriage, which had been placed on the raft with a 100-ton Armstrong breech-loading gun, Lepanto type, drawn up as before at a range of 133·7 metres (438·7 ft.) In both rounds with the 15^{cm} gun the projectile was a Krupp hardened steel shell, made up to 36 kilogs. (79·37 lbs.).

The programme consisted of two kinds of test. (1) Krupp 15^{cm} projectiles (5·9-in.) should be fired taken from a batch whose excellence had been established in the recent competition at Muggiano. This had been suggested by M. Otto Budde, Krupp's representative. If these projectiles should break up in the same way as those already fired from the 100-ton gun, the natural inference would be that there was no ground for supposing that the large projectiles were inferior in quality, at all events the fact of their breaking up affords no such ground. It must be conceded that it was most reasonable that Italian officers should wish for a guarantee on this head, seeing that the difficulty of making good steel projectiles increases with the scale on which they are made to such an extent that it is desirable that those of any weight approaching 1000 kilogs., or 2200 lbs., should establish their character in every possible way.

The second test was the firing of a steel projectile supplied from St. Chamond for the 100-ton breech-loading gun. This would furnish a comparison between the large projectiles made in France and Germany. Thus, supposing it were to be concluded that Krupp's large projectiles had broken up more than his small ones, or had shown an inferior fracture in any part, it would be possible to see whether the French manufacturers had been more successful on this scale.

This trial, then, while it had a bearing on the resisting powers of Grüson's shield, did not touch the question of its acceptance. This had been settled at the conclusion of the trial in April.

First round with 15^{cm} gun (No. IV. in all).—Charge 15 kilogs. (33·06 lbs.) progressive Fossano powder (20–24^{mm}); striking velocity, 500 metres (1640·45 ft.); striking energy, 459 metre-tons (1482·1 foot-tons). The projectile struck 13^{cm} above the edge of the *avant cuirasse* (glacis plate) at 86^{cm} to the right of the centre of the shield, at a striking angle of 44 deg. The projectile broke up, making a small chip in the shield.

Second round (No. V. in all).—Charge 18 kilogs. (39·68 lbs.), progressive Fossano powder (20–24^{mm}); striking velocity, 564 metres (1850·43 ft.); striking energy, 584 metre-tons (1885·6 foot-tons). The projectile struck 23^{cm} above the edge of the glacis plate and 102^{cm} to the right of the centre of the shield; angle of incidence, 50 degs. 30 mins. The projectile broke up, and produced, about the part marked V. (Fig. 1, p. 29, II.), a chipping off the surface.

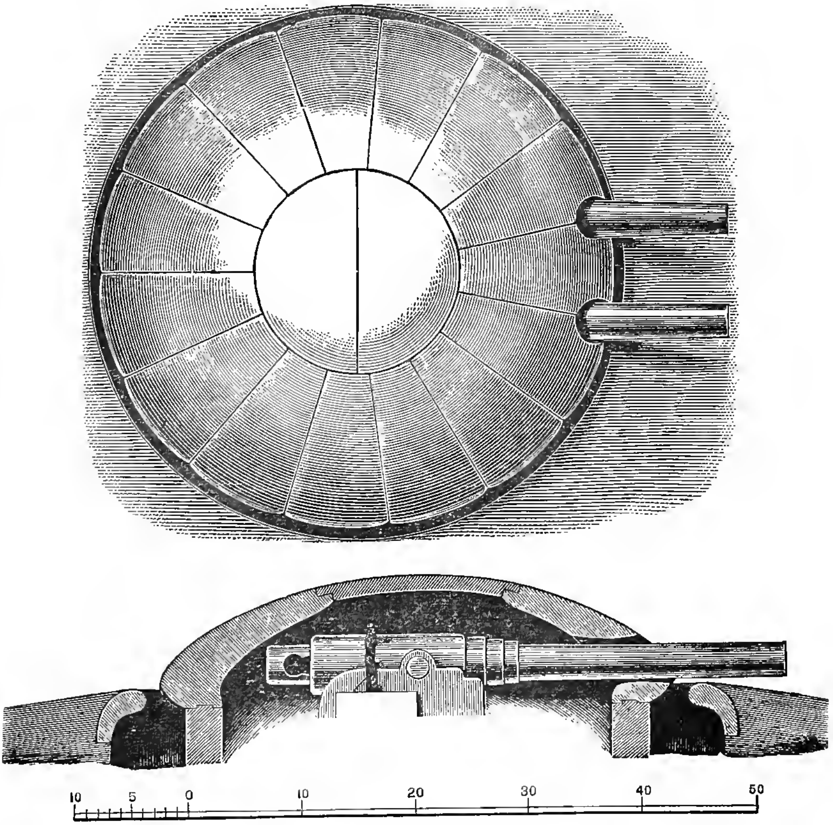
The fourth round from the 100-ton gun (Round VI. in all) was now fired. Charge, 375 kilogs. (826·7 lbs.). Westphalian (cocoa powder); projectile, hardened steel, St. Chamond; calibres weight, 1000 kilogs. (2204·6 lbs.); initial velocity, 539 metres; striking velocity, 535 metres (1755·3 ft.); striking energy, 14,603 metre-tons (4715·4 foot-tons.) The shot was aimed high up at the point marked with a cross in Fig. 1, but the movement of the raft by the swell of the sea caused the projectile to strike close to the spot struck by the second round fired in April (*see* VI. on Fig. 1.) Owing to the injury the shield had suffered already, the surface was struck nearly normally—that is, at between 80 and 90 degs. The projectile broke up and dislodged portions of plate of different thickness up to 50^{cm}. One crack was lengthened, and some other local injury effected in front (*vide* Fig. 1.) At the back were two new cracks μ and ν and also o, also a larger scale between γ and δ was detached (*vide* Fig. 2), the small fragments of which it was composed fell vertically, and would not have injured men behind the shield. A small triangular portion above a projected about 6^{cm}. The lower portion of the plate had given back and projected beyond the upper part about 3·5^{cm} (1·4-in.) along crack γ, about 6^{cm} (2·4 in.) along crack ϵ, and 4^{cm} (1·6-in.) along crack o. The left buttress or shoulder was slightly displaced. The general condition of the shield was good. In spite of the fracture of the left bearing plate or cheek, and some displacement, the shield might have borne a further attack; but there were no more available projectiles for the 100-ton gun.

The object of this programme may be said to have been attained, as far as the chief practical bearing of it for Italy is concerned. Clearly all steel hitherto known must be expected to fly in pieces against chilled-iron, whether the projectile be large or small. The St. Chamond projectile, however, did not strike in such a way as to admit of a comparison of its effect with that of any of Krupp's projectiles. The comparatively small effect produced by the French shot, when striking exactly on the most injured spot in the shield, speaks well for the resisting powers of the latter even when much cracked.

To pass on to the turrets which the shield represents. As before said, there are the two turrets to protect Spezia harbour, each mounting two 119-ton Krupp guns, whose exact power cannot be ascertained certainly, seeing that there are different estimates, and that Herr Krupp not long since declined to give authentic information. They have been fired at Meppen with results which are not made public. So far as can be learned, the power of this gun is nearly the same as that of the 100-ton breech-loading Armstrong, but inferior to the 105-ton and 110-ton breech-loading Armstrong guns.

It may be well to point out one thing about which there seems occasionally to be some confusion, namely, that while the attack of armour may be a very telling illustration of the power of a gun, it is no test of the gun, strictly speaking. The power of the gun is fully told by the energy of the projectile when leaving the muzzle. What happens after that concerns the projectile and the plate, but clearly has no further connection with the gun itself. In this trial, for example, the gun is not concerned, at all events directly, in whether the shield is broken or not. This may be a question between Krupp's projectile and Grüson's shield, or more really between Grüson's shield and what might be expected from Schneider's, Brown's, Cammell's, Marrell's, or Terni armour formed into some equivalent shield. Then, again, the effect of a steel projectile as compared with a chilled-iron one, when attacking chilled-iron armour, naturally arises in considering

Fig. 12.



such a trial, and this is the especial point that interests us in England, and in this Elswick may be interested as manufacturers of projectiles. As gun makers they may be interested in the eventual consideration of what guns may be able to effect against shields, but *immediately* and *directly* their success as gunmakers is limited to the energy with which they can discharge a projectile of a given calibre.

Fig. 12, p. 33, II., gives a rough plan and section—drawn from verbal description—of the complete turret. It will be seen that there are fifteen segment or sector-shaped shields, with two centre plates forming the crown. The interior diameter is 10 metres—32·8 feet. The periphery is not a circle, but is formed of fifteen arcs of circles, each struck with a radius of about 15 feet or 16 feet, giving an outline suggestive of that of a pomegranate. Of the fifteen plates, twelve are similar to the shield under trial, each weighing about 87,950 kg. or about 86·56 tons. The remaining three are lighter, being pierced by the gun ports; the lightest being that between the ports. The twelve unpierced plates will thus weigh about 1039 tons. The two centre or crown pieces weigh together 130,000 kg., or 128 tons. The total weight of the armour is 1,400,000 kg., or 1378 tons. This leaves 211 tons for the three pierced plates, two of which will be something over and the other something less than 70 tons. The entire running weight of shield—1378 tons—is to be supported on an iron ring.

The machinery for working the turrets is supplied by Sir W. Armstrong and Co.

CHAPTER III.

BUCHAREST CUPOLA COMPETITION.[1]

BY

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THE general idea of the defences of Bucharest appears to be to create a place of arms in which the whole military strength of the kingdom can be gathered. It is recognized that the military position of Roumania is distinctly dependent; but the absence of any permanent defences practically prevents the choice of an ally. The Eastern frontier is so open that Bucharest could be occupied by a Russian army in a few days. It is argued, therefore, that by the creation of a place of arms, time would be gained to enable any power to give practical effect to an alliance. Bucharest was selected as the centre of the wealth and commerce of the country, as well as the junction of its railways. The position possesses no natural advantages, and the opinion has been expressed that a second place of arms should at least be formed on the Kronstadt Railway among the southern spurs of the Carpathians.

The decision to defend Bucharest having been taken, General Brialmont was asked to furnish designs and advise generally upon the scheme to be adopted.

As far as could be gathered, the following are the principal features of his proposals:—

The main defence is to consist of 18 large forts, at about 4000 metres interval, supplemented by intermediate batteries.

The forts are to have earth scarps and a detached wall flanked by counterscarp galleries with three embrasures—two firing in front and one behind the wall. The counterscarps are to have arched counterforts. The detached wall is to be protected from projectiles grazing the crest of the glacis, with a descent of 1 in 3. On the flanks, it is considered that the wall is sufficiently protected if it cannot be hit at an angle exceeding 45 degrees. In front, there will be a second glacis, covering wire entanglements and other obstacles. On the flanks, wing batteries and rifle trenches will be provided. The parapets are to be constructed of sand, with a layer of vegetable mould on the top, the exterior slope being about $\frac{2}{3}$.

An interior reduit contains three turrets or cupolas, and a battery for four howitzers. The latter are to have central pivots and hydraulic buffers. Between each adjacent pair there is a hollow traverse, capable of containing the howitzer. At the back of this chamber there is a small ammunition store.

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General Brialmont, in his work "*La Fortification du temps présent,*" expressed an opinion in favour of turrets for land defence, and reproduced the designs of the St. Chamond firm, including a project for a moveable shielded battery running on rails laid behind a parapet. It was decided, therefore, that a competitive trial should take place between the rival firms of Grüson and St. Chamond, from which it was expected that data leading to a definite decision would be obtained. The total cost of the experiment was nearly £40,000; but as yet no final decision as to the armament of the forts seems to have been taken. For the armament of the intermediate batteries on the fronts most liable to siege, rifled mortars fixed in a spherical mass, pivoting under a horizontal shield, and thus presenting no open port, according to a design of the Grüson firm, appear to have been recommended. As to the ditch-flanking armament no decision has been arrived at; but some form of machine or quick-firing gun will doubtless be adopted.

Three of the new forts only had been commenced at the time of our visit, situated as follows:—

1. Chitella Fort on the road and railway leading to the Austrian frontier at Kronstadt.
2. On the road to Mogosoie, 2 kilometres from Bucharest, and due north of the "chaussée."
3. At Goulaqui, on the west of the town, between Chitella and Cotroceni.

Of these, the two first named are the most advanced, the ditch excavation being nearly completed.

DIARY OF EXPERIMENTS.

18th December.—Inspection of cupolas. Fired from both cupolas with "projectiles fictives."

19th December.—Fired 10 salvoes for accuracy.

21st December.—French turret fired 25 salvoes, and *22nd December,* German cupola fired 25 salvoes for rapidity and accuracy.

23rd December.—Continuation of practice for accuracy. Each cupola fired 10 rounds.

24th December.—Practice at a target suddenly presented. Each cupola fired 3 salvoes.

26th December.—Practice at French turret with de Bange 155^{mm} and Krupp 15^{cm} guns; 42 rounds fired.

27th December.—Practice at French turret continued; 9 rounds fired. Practice at German turret with de Bange 155^{mm} and Krupp 15^{cm} guns; 27 rounds fired.

Practice for accuracy from French turret; 5 rounds fired.

28th December.—Practice continued; 58 rounds fired. Practice for accuracy from German cupola; 6 rounds fired.

29th, 30th, and 31st December.—Practice at cupolas with 21^{cm} Krupp rifled mortar; 14, 56 and 44 rounds respectively.

1st January.—Ditto; 50 rounds fired.

2nd, 3rd, and 4th January.—Dismounting guns in cupolas, and their replacement by dummies, and construction of siege battery at 50 metres.

5th January.—Practice at embrasures of both cupolas; 11 rounds fired.

7th January.—Practice at glacis plate of French turret. 20 rounds fired.

8th January.—Practice at glacis plate of German cupola; 21 rounds fired.

11th January.—Practice for breaching German cupola; 50 rounds fired.

14th January.—Practice for breaching both cupolas; 36 rounds fired.

15th January.—Ditto ditto French turret; 19 rounds fired.

16th January.—Guns remounted in cupolas.

17th January.—Practice for accuracy and rapidity, German cupola; 20 salvoes fired.

20th January.—Practice for accuracy and rapidity, French turret; 21 salvoes fired.

22nd January.—Practice against a wrought-iron plate of German cupola; 21 rounds fired.

23rd January.—Fired 7 rounds, filled and fuzed shell, from 21^{cm} Krupp rifled mortar; for effect in soil.

GERMAN CUPOLA.

General Description.

The pit or emplacement consists of a single circular chamber 19 ft. 6 ins. in diameter, with brick walls about 5 ft. thick. The floor level is 3 ft. 6 ins. below the natural surface of the ground. The pit is entered by steps through a door 5 ft. wide. There are 14 recesses, 3 ft. high by 2 ft. broad, and 18 inches deep, evenly spaced round the interior wall. Each recess has one shelf and can hold altogether 24 projectiles, so that a total of 168 rounds for each gun can be stored in the emplacement.

The glacis plates rest on the top of the wall which ends at the level of their lower surface. Outside these glacis plates, there is a mass of concrete 9 ft. thick, measured along the superior slope from their inner edge. The exterior slope of this concrete is 35 degrees, and in front is a thick parapet of sand on the side which was attacked. The roller path (*a*) and the gunmetal training arc (*b*) are fixed to the inner top angle of the wall. The socket of the screw pivot (*c*) is bedded in concrete, and there is a false floor boarded over except in the centre, where the fixed internal toothed wheel of the traversing gear and the pivot are left bare.

There was ample space for moving about freely in the emplacement, and for the operations of loading and traversing.

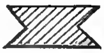
Description of Cupola.

The cupola consists of two armoured portions—(1) the glacis plates set in concrete and forming a complete annulus round the pit; (2) the curved shield, free to turn on a central pivot, and covering the two guns and mechanism.

Glacis.

1. The glacis, or *avant cuirasse,* consists of eight cast-iron blocks or segments set in concrete, and formed as shown in Fig. 8, p. 39. The joints are run with zinc. The two rear blocks which were to be attacked, had central ribs in addition, apparently with a view to give them greater strength. The total weight of the glacis ring is 70 tons, and its internal diameter 5·93 metres (19·45 ft.)

2. The curved shield consists of six segmental side plates and a hexagonal roof plate. The front plate which is pierced for the two guns, as well as the plates on either side of it, are of wrought-iron. The three remaining side plates are compound. The thickness of all the plates is 20^{cm} (8 in.) The total weight of the shield is 46 tons. The curvature of the plates is such that the angle of impact of a projectile striking them horizontally can never exceed 25 degrees. The portion of the front plate surrounding the two gun ports is strengthened by swelling out the metal round the openings at the top and sides, as indicated in the section, Fig. 8, p. 39. The wrought-iron plates are bent by hydraulic machinery. The compound plates are made on Mr. Wilson's principle by running the molten steel on to their upper surface. The plate is made up of three qualities of metal as follows:—7^{cm} hard steel face, 3^{cm} soft steel, 10^{cm} wrought-iron. The mass is then re-heated, bent by hydraulic power, and subsequently annealed. The cost of the plates is materially enhanced by the great waste of metal incurred by cutting off the corners in shaping them. The plates so made are united to form the shield by being bolted to an inner skin composed of two layers of wrought iron-plate, each 0·8 in. thick. These layers are rivetted together, and through them pass five bolts of steel, the female screws of which enter half through the main armour plates. The bolts are rivetted up from the inside. The side armour plates are further held together at each junction by one steel wedge of the form shown in sketch, and abut against the central hexagonal plate, but are not keyed to it.



The most striking principle in the design of this cupola is the method of supporting the shield. The whole weight of the moveable portion of the structure is taken on a central pivot (Fig. 8) 8 ins. in diameter. The pivot is screwed into the socket piece and the collar is keyed on to it. This collar is provided with a worm wheel on its outer circumference, which engages an endless screw. By means of a ratchet lever, the worm wheel can be turned, thus raising or lowering the pivot and with it the whole superstructure. The total vertical movement which can be given is 6 ins., and this allows the shield to be lowered down upon the glacis plates or elevated into the firing position. The whole structure is thus free to rock on the rounded top of the pivot but the lower edges of the shield are prevented from coming in contact with the glacis by legs resting on trucks running on a circular racer (*r*) and set in journal boxes provided with strong volute springs. These springs thus serve to cushion the vibratory motion set up by the force of recoil, or by the impact of projectiles. The maximum movement measured at the top of the shield is stated to be only about 2·5^{cm} or 1 in., but appeared to be considerably greater.

Pivoting arrangements.

Recoil.

The whole stress of recoil is transmitted to the general structure of the turret by a pair of vertical arcs (*h*) in rear of the breech of each gun. A ring (Fig. 8) is shrunk on to the chase at a short distance from the muzzle, having trunnions which rest in recesses formed in the inner skin at the sides of the ports. These recesses are open in rear, so that they allow the trunnions to pivot freely, and at the same time, by moving them a few inches to the rear, they clear the recesses when it is required to dismount the guns. In rear of the breech of each gun is a powerful capstan-headed clamping screw, by which all play between the guns and the arcs is taken up, so that hammering action is avoided.

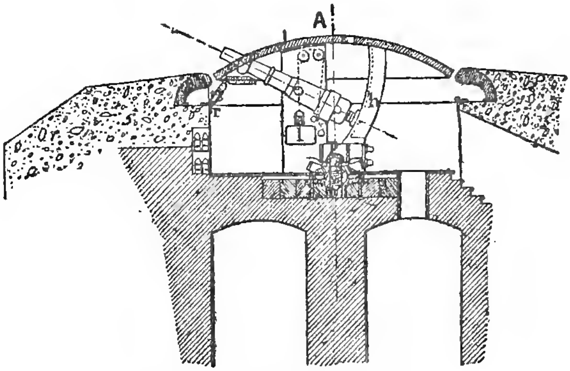


FIG 8: SCHUMANN GRÜSON CUPOLA

Elevating gear.

Quadrant elevation is given by graduations on these arcs. The preponderance of each gun measured about the front pivot, is slightly overbalanced by a counterpoise weight (*l*) suspended by two chains, each passing over two pulleys, and attached to an iron cross-bar passing under the gun just in front of the breech mechanism, fixed in position by a steel strap. In order to give elevation, the breech is hauled down by a chain wound round a ratchet windlass.

Turning gear.

Rotation is imparted to the cupola by a pinion gearing internally into a horizontal toothed wheel fixed into the floor of the gun pit.

The pinion is actuated by winch handles through simple bevel gearing. This gear, by means of a clutch, can be rendered available for winding in the falls of the tackle used in mounting and dismounting the guns. Four bent lever arms are attached to the legs containing the journal boxes, and can be used, if necessary, to assist in traversing.

Close under the circular racer on which the trucks of the shield ride, is fixed a brass graduated circle, over which travels a pointer attached to the shield. This circle reads to degrees and 6-minute divisions. The maximum elevation is 25 degrees, and depression 5 degrees.

Sighting. The guns are supposed to be parallel. In rear of the centre of the top of the shield and over the medial line of the guns, is a hole sufficiently large to admit of the head of the No. 1. At the front of this manhole, and inconveniently near to the eye of the No. 1, is a hinged gunmetal sight, furnished with a deflection leaf, and free to slide up and down a slotted bar. The movement is not for the purpose of giving elevation, this being provided for as already described by the vertical arc, but for convenience in laying on objects at different levels; the sighting is, in fact, merely for line. Access to the sighting hole is provided for by a light iron ladder between the guns.

Loading. The loading is performed at an elevation of 14 degrees, the loading position being indicated on the steel vertical arcs by a broad red band, so that the guns can at once be adjusted to it. The projectile and charge are inserted by means of a loading tray between the arcs and through the breech clamping screw, and are separately sent home by a short rammer. The guns can be loaded with equal facility at all angles of training.

Guns. The guns are 15^{cm} (6-in.) B. L. of Krupp manufacture, 25 calibres in length, and weighing about 3 tons. The common shell weighs 69·3 lbs., bursting charge $2\frac{3}{4}$ lb.; the steel shell 88 lb., bursting charge $5\frac{1}{2}$ lb.; steel armour-piercing shell 86·9 lb., bursting charge $1\frac{1}{4}$ lb.

The maximum charge of the gun is 19·8 lb., cocoa powder.

Earlier Designs. The cupola above described constitutes a complete departure from the earlier designs of the Grüson firm. Starting with structures built up entirely of chilled cast-iron blocks, wrought-iron was first introduced for the roof plates. In 1882, a wrought-iron umbrella-shaped cupola, designed by Major von Schumann of the Prussian Engineers, was tried at Kümmersdorf, the design being to some extent based on the experience gained at Tegel in 1870–1, and at Maintz in 1866. The Tegel turret was made of wrought-iron, contained two guns, and nearly resembled the ordinary ship's turret. The desirability of reducing the cost and the weight led to the adoption of the non-recoil system, which allowed the protected space to be smaller in extent; while the Tegel experiment, in which projectiles striking the plates at an angle of 27 degrees produced extremely little effect, pointed to the utilization of wrought-iron in plates with double curvature. Thus the Kümmersdorf cupola was made of wrought-iron plates bent to a spherical form, with an exterior radius of 15 ft. The maximum angle at which 15^{cm} shells fired at 1000 metres could strike this cupola was 35 degrees, and the thickness of the lower edges was $7\frac{1}{8}$ ins. At the level at which projectiles could strike only at an angle of 25 degrees, the thickness was reduced to 4 ins. The curved shield was formed in laminæ, two of 2 ins. thickness, strengthened internally by two $3\frac{5}{8}$ ins. round the lower portion. The Kümmersdorf cupola contained only one 6-in. gun mounted in the same way as those at Bucharest. There were no curved cast-iron glacis plates, but instead, a vertical ring of wrought-iron 4 ins. thick.

This cupola was severely tested. A hundred rounds were fired from it at elevations between 4 degrees and $12\frac{1}{2}$ degrees without injury. Eighteen long 6-in. shells were then fired at it, of which several hit the same spot, causing no damage. Seven chilled shell were then fired also without any real effect. Eight 6·7-in. (17^{cm}) chilled shell were tried, some of which striking at angles below 30 degrees produced no effect. Others, striking low down near the rim of the cupola, damaged it considerably, and proved that the protection conferred by $7\frac{1}{8}$ ins. of wrought-iron was insufficient against the 17^{cm} gun. After firing 11 salvoes of chilled shell at 1000 metres range from four 6-in. guns, by which no satisfactory hits were obtained, the attacking battery was moved up to 300 metres, and two effective salvoes were then fired without injury to the structure.

The cupola was then attacked by the $8\frac{1}{4}$-in. (21^{cm}) rifled mortar at 65 degrees elevation, firing 176 lb. shells. Four effective hits were obtained, producing merely slight indents. The turning gear of the cupola was tried and found to be uninjured. A complete rotation was made in 36 seconds. Finally, 50 rounds were fired from the cupola gun at elevations up to $24\frac{1}{4}$ degrees, the last 25 rounds for rapidity. The rate of fire was a little less than one round per minute, and the diagram obtained was very satisfactory.

The Commission which carried out the Kümmersdorf experiments made a variety of recommendations of which the following were the most important :—

1. The shield should be made up of single thicknesses of plates instead of laminæ.

2. A flatter curvature towards the lower edge of the cupola appeared desirable.

3. The lower edge of the cupola should be better protected by being sunk below the glacis ring.

4. The employment of concrete under the shield to balance the whole structure about the central pivot should be avoided, if possible.

These recommendations, together with others, were embodied by Major von Schumann in the design of the Bucharest cupola, so that the latter may fairly be regarded as representing the results of much previous experience. The compound plates forming the rear half of this cupola were apparently introduced in accordance with the views of the Roumanian Commission.

It is to be observed that cupolas built on the principle of transmitting the recoil direct to the whole structure are termed by the makers "shield mountings" (Panzerlaffete), and that this principle was first tried at Kümmersdorf.

RESULTS.

18th December, 1885.—Two rounds were fired from each gun with full (19·8 lb.) charges at the maximum angles—viz., 5 degrees depression and 25 degrees elevation, with "projectiles fictives" weighing 90¼ lb. These projectiles were constructed to break up at the muzzle in order to avoid the necessity for clearing the range. The gear worked well throughout.

Series (a).

19th December, 1885.—Trials for accuracy—Ten salvoes at a target 10 metres by 6 metres. Range 2,500 metres. In this series five salvoes from each turret, allowed as sighting shots, were first fired.

The oscillation of the turret being considerable, and the firing being by word of command, and, therefore not always synchronous, the accuracy of the second gun was doubtless affected.

Series (b).

21st December, 1885.—Trials for rapidity and accuracy—After 3 salvoes (sighting shots), 25 salvoes were fired, the laying being corrected as in Series (*a*) by the telephoned result of each.

Total time occupied in firing 25 salvoes or 50 rounds, 2 hrs. 27 mins. 20 secs.

The times lengthened towards the end of the series. This was due to the traversing numbers, who were not relieved until after the 12th salvo, becoming fatigued.

Series (c).

23rd December, 1885.—Additional trials for accuracy, apparently ordered because the brown powder had now arrived.

Series (d).

24th December, 1885.—The practice was apparently intended for a comparative trial of the relative facility for rapidly directing the fire of the two turrets. This series must be regarded as unsatisfactory from every point of view, and so far as testing the power of firing from turrets—the object which the Committee had in view—was practically worthless.

Series (e.)

27th and 28th December, 1885.—(Fig. 2, p. 43).—The object of this series was to obtain 30 direct hits on two of the three compound plates forming the rear portion of the cupola, at a range of 1000 metres. To effect this 85 rounds had to be fired—viz., 27 on the first and 58 on the second day.

The cupola was turned so that the medial line of the rear centre (compound) plate faced the attacking guns.

The total number of hits obtained was 35, but of these five were *en ricochet.*

The three guns used for the attack were—

1 de Bange, 155$^{\text{mm}}$ } of the same model as those mounted in the
2 Krupp, 15$^{\text{cm}}$ } turrets.

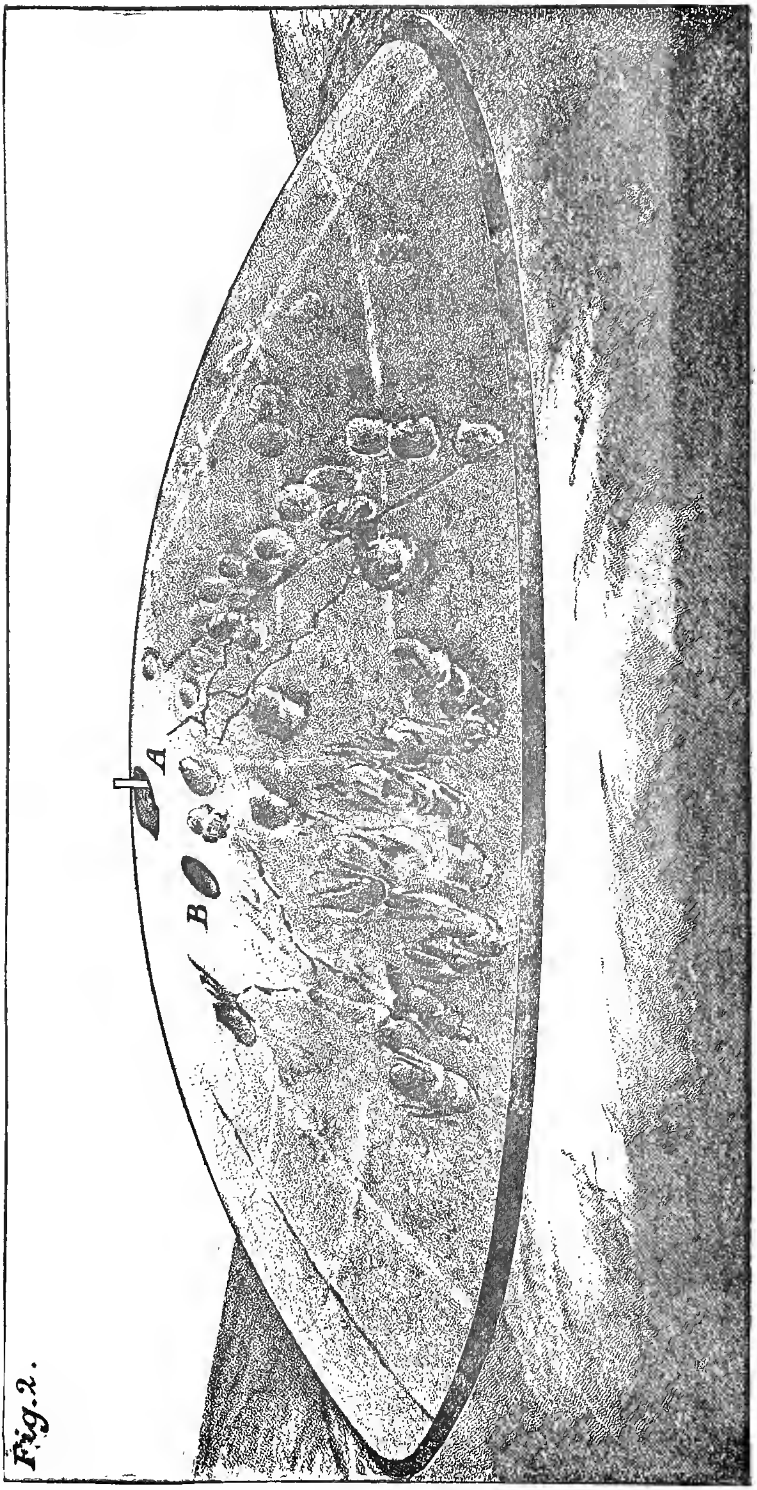


Fig. 2.

The firing was sometimes by single rounds, varied by salvoes of two and three guns, no apparent principle being followed.

The French gun, de Bange, was mounted on a siege travelling carriage.

The German gun was mounted on a siege traversing platform of the usual Krupp pattern, on A racers.

The projectiles were all steel, of Krupp and St. Chamond manufacture.

The weights were as follows, sand being substituted for the bursting charge:—

Krupp—39 kilos. (85·8 lb.) filled; bursting charge 1·7 lb.
De Bange—40·9 kilos. (89·98 lb.) filled; bursting charge 1·7 lb.

The powder charge for the German gun was 9 kilos. or 19·8 lb. of brown prismatic powder, for the French gun the same weight of Sevran-Livry pebble.

The distribution of hits at the conclusion of the 85 rounds, and the general appearance of the turret is shown in Fig. 2, p. 263.

The general effect of single shots was to make a shallow scoop, Fig. 2, p. 263, with a maximum depth of indent of about ¾ in., and it would not appear that the depth varied according to the angle of impact with the curved surface of the plate.

A gradual cracking of the steel face of the plate took place during these rounds, but at this stage there was no actual separation from the wrought-iron.

The rotation of the cupola was in no way affected by the foregoing series.

No cracks were visible in the interior; but, at the 20th hit, one of armour bolts was sheared, and the nut and washer, weighing 33 lb., fell on the gun floor. A cast-iron spur wheel of the traversing gear was also found to be broken. One of the hand levers for turning the cupola was broken off.

Series (*f*).

28*th December*, 1885.—At the conclusion of the foregoing series, six rounds were fired from the guns in the turret to ascertain whether the gear was in working order. The turret had to be rotated by hand, as the broken wheel was not replaced till next day.

Series (*g*).

31*st December*, 1885 *and* 1*st January*, 1886.—This series was intended to ascertain the effect of high-angle fire from the 21^{cm} Krupp rifled mortar, with steel and cast-iron common shell, weighted up to 91 kilos. (200 lb.), at a range of 2,510 metres (2,745 yards).

It will be seen that the shooting on the whole was fairly good, the maximum lateral dispersion, omitting two wild rounds, being 50 metres. Two shells fell on the parapet and one on the top step of the entrance; unfortunately none struck the cupola itself.

Series (*h*).

5*th January*, 1886.—This firing was at the wrought-iron port plate, on which seven direct hits were obtained.

The guns in the cupola had been dismounted and replaced by solid cast-iron cylinders about 5 feet long, strutted against the steel arcs by rounded timbers.

The general effect of these rounds will be found in Fig. 4, herewith.

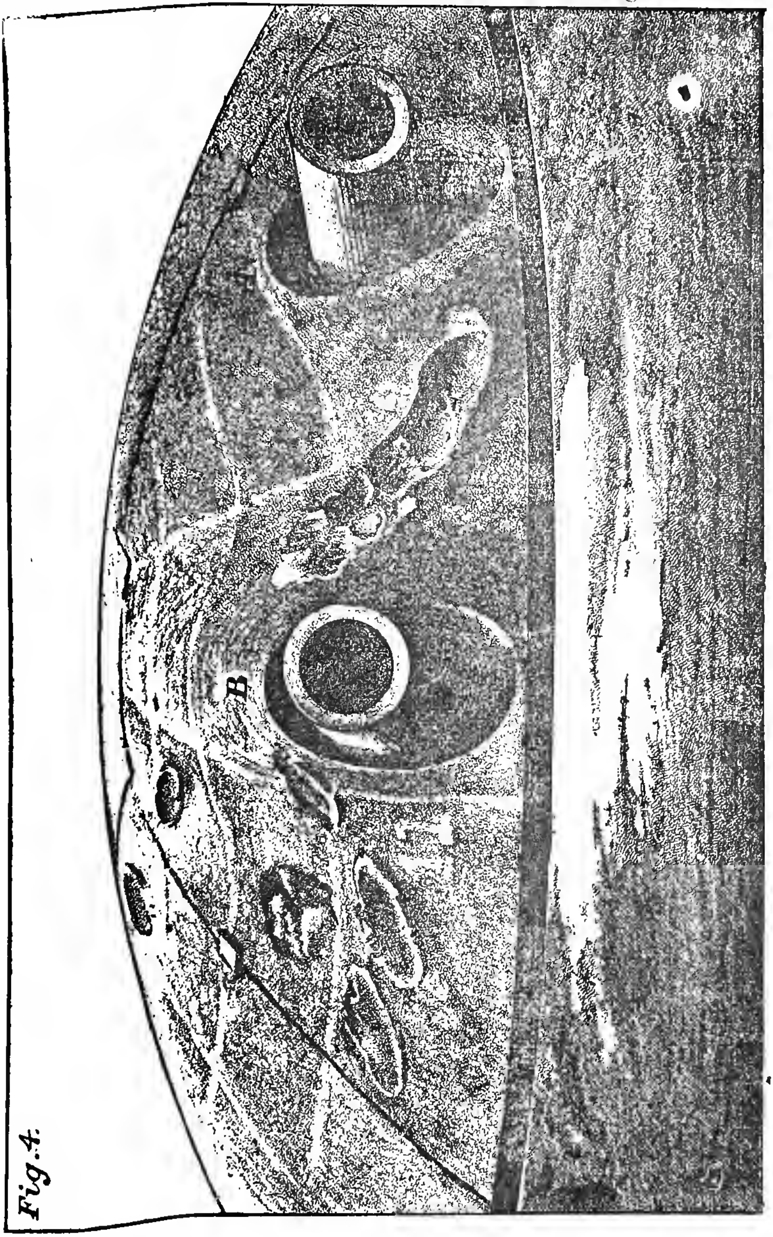


Fig. 4.

Inside the cupola, one armour bolt between the ports fell out, and two skin bolts sheared. The threads of the armour bolt, which were evidently too fine, were uninjured.

Series (i)

8th January, 1886.—This series was intended to test the resisting power of the chilled-iron glacis plate. The 15^{cm} Krupp gun was used throughout.

The sector fired at was practically breached near the bottom. The attacking gun was mounted on a piece of built-up ground, and its axis was a little above the level of the glacis. The line of fire had an angle of depression of 1 degree 22 minutes, giving a maximum angle of impact on the curved face of about 70 degrees.

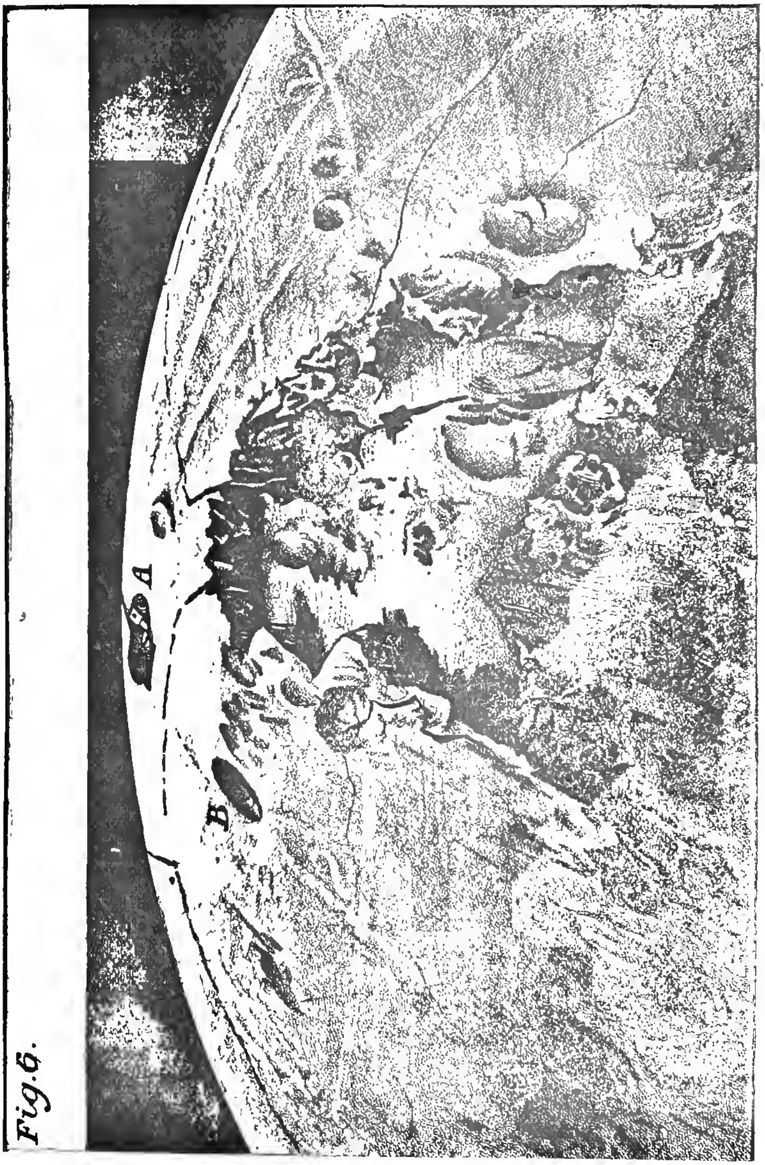


Fig. 6.

Series (j.)

11*th and* 14*th January,* 1886.—The Committee decided to continue the practice of the 27th and 28th December, 1885, at the compound plates, until a breech was effected. The practice was extremely accurate, 35 hits being obtained, of which 7 were ricochets. The general effect may be summed up as follows :—

The steel face, which had been previously cracked in several places, began to strip at the third hit, the tendency to lamination showing itself between the two qualities of steel as well as between the mild steel and wrought-iron. The cracking and stripping proceeded gradually throughout the practice, the whole area of wrought-iron exposed at the conclusion of the series being about 5 ft. 6 ins. by 2 ft.

Fig. 6, p. 46, shows the appearance of the shield and the direction of the principal cracks developed. As a rule, the cracks did not extend to the wrought-iron ; but, at the proper left top corner of the plate, a four-sided piece, area about 12 ins. square, was completely detached remaining, however, in *sitû,* sustained by the skin. A single projectile striking this portion of the shield would probably have penetrated into the cupola. The total number of hits sustained by the rear centre compound plate was 31, including ricochets.—(*Vide* Figs. 4 and 5, herewith).

In the interior a considerable number of skin rivets and bolts were sheared, but appeared to have merely dropped down on the floor, and in no case to have flown with any force.

Fig 5

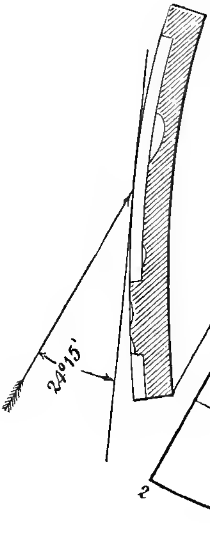
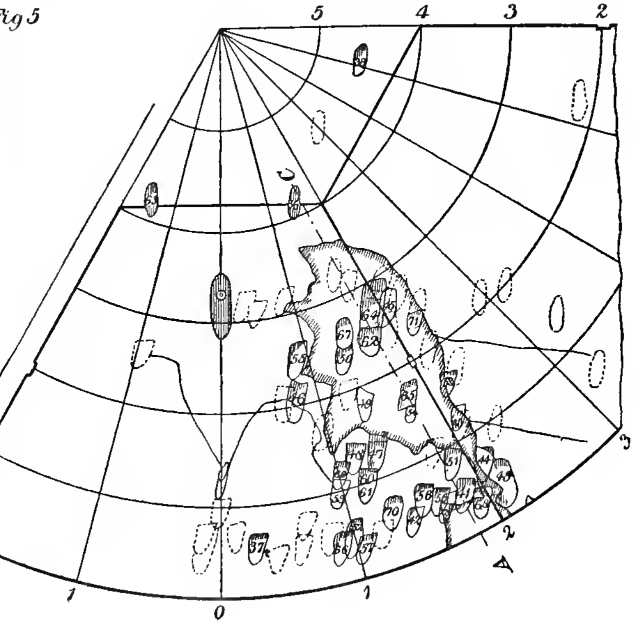


Fig 4



Series (k).

17th and 20th December, 1885. This series of 30 salvoes was intended to test the working of the gear after the trials to which the cupola had been subjected in Series (*e*) and (*j*).

The shooting was evidently not greatly affected by the battering the cupola had received, but was indifferent.

The only damage the cupola sustained was the shearing of one nut in left arc of left gun; this was done by last salvo at 5 degrees depression.

Series (l).

22nd January, 1886.—This was in continuation of Series (*h*), cast-iron dummies taking the place of the guns as before. Five rounds were fired from 15^{cm} Krupp gun at the wrought-iron embrasure plate at a range of 1000 metres, with a view of obtaining a hit at the edge of the proper left port.

The damage inflicted by the first four rounds was very slight. The fifth round, had the gun been mounted, would have put it out of action; while there can be little doubt that the spar interposed between the dummy chase and the arcs saved the latter from such serious damage as would have prevented another gun from being mounted. The uninjured gun might in this case have remained serviceable. If, however, either of the cupola guns were struck fair on the muzzle, the injury transmitted to the whole of the gear might evidently suffice to disable the cupola. As it was, the only damage done, other than to dummy, was the breaking, as shown in sketch, of the small bracket supporting the right auxiliary trunnion, and this could have been readily repaired.

Series (m).

22nd January, 1886.—For this practice, the turret was turned so that the centre of the left front (wrought-iron) plate was turned towards the attacking gun. 21 rounds were fired, of which 15 struck the plate, and two the glacis plate, in line. As far as could be ascertained, the majority of these steel shells broke up on the armour plate. This no doubt was due to the shell, after deflection of the point, striking an independent blow on the plate with the base, and cross breaking. These same shells, striking a wrought-iron plate direct, either penetrated, or were thrown back unaltered in shape.

GENERAL REMARKS.

This cupola cannot be considered apart from the leading principle invented by Major Schumann, in which the guns, gear and shield form part of a system rigidly connected, the whole force of recoil being absorbed in the oscillation of the compound mass.

The system possesses certain marked advantages:—

1. It lends itself to the employment of a turtle-back, or umbrella-shaped shield, which is comparatively inconspicuous, difficult to hit, and almost proof against direct fire.

2. The guns being nearly muzzle-pivoting, not only is the size of the ports reduced to a minimum, but the exposed portion of the guns themselves becomes comparatively small.

Advantages.

3. By the absence of a carriage, the complicated gear entailed by the necessity of providing means of controlling the recoil at all angles of elevation is avoided. Thus much valuable space is saved, and there is plenty of room for the operation of loading, which can be performed by hand from the floor level at any position of the cupola, as well as for the storage of a large number of rounds. The traversing is also performed in the chamber in which the guns are mounted, so that the construction of a lower chamber with speaking-tube communication is rendered unnecessary. The operations of mounting and dismounting the guns are remarkably simple.

4. The method of mounting allows a range of 30° of vertical arc.

The disadvantages are :—

Disadvantages.

1. The breech of the gun has to be clamped at the required elevation for each round, and should the capstan-headed clamping screw be not properly set up, a violent blow would be dealt to the steel arcs in rear, which might distort or displace them.

2. The adjustment of the guns depends upon the maintenance in the same relative position of the steel arcs and of the trunnion brackets. The upper extremities of the arcs and brackets are independently attached to the inner boiler plate skin, and distortion of this skin may therefore destroy the adjustment. The skin being attached by armour bolts to the shield plates, is liable to distortion when the latter are hit. A considerable displacement of the plates took place during the trial.

Distortion of the skin may produce the following results :—

(*a.*) The parallelism of the guns may be thrown out.

(*b.*) The direction of either or both of the guns, with respect to turret sights and to the horizontal arcs, may be affected; moreover, these sights being attached to the roof plates, are liable to independent displacement from blows on the shield.

(*c.*) Any vertical displacement of the supports of the front trunnions would vitiate the elevation given on the arcs.

3. The oscillation set up by firing exercises a disturbing effect on the shooting for the following reason :—

(*a.*) Unless both guns are fired at the same instant of time, or the second when the oscillations set up by the first have subsided, it is evident that the angle of elevation of the last gun fired will be incorrect. Electric salvo firing is therefore a necessity. This fact was apparently not recognized during the experiments, and the firing throughout was by word of command, the interval between the rounds being, in many cases, well defined. The want of accuracy shown in the practice from the cupola guns was probably due in a great measure to this cause. The Kümmersdorf cupola had only one gun, and it is stated that Major von Schumann greatly prefers this arrangement.

(*b*.) The repeated oscillation of the cupola, the blow being always delivered in the same direction, tends to give a permanent set to the volute springs supporting the rear guiding trucks. That this occurred during the experiments was evident. At the conclusion of the practice, the lower rim of the shield was visibly thrown out of the horizontal plane, and the whole mass of the cupola had acquired a permanent cant to the rear. If then, elevation was given by arc, it would be incorrect, and it would be necessary to lay the guns by quadrant.

4. The error in direction, due to movement in rotation during the interval between the rounds, is common to all two-gun turrets, but in the case of an oscillating cupola this movement becomes more complicated.

5. Indirect laying for direction is provided for by means of a pointer attached to the inner skin, and travelling over a fixed graduated arc in the inside of the pit. If this pointer is adjusted close to the arc, it is liable to be bent out of shape by striking the arc on recoil; if at a safe distance, accurate reading is rendered impossible by parallax. During the experiments the oscillations of the cupola caused the horizontal arc to be freely hammered by the pointer.

Shield. Each shield plate is attached to the inner skin by armour bolts screwed half-way into the thickness of the metal. The threads on these bolts were so fine that in some cases concussion of the shield, due to a blow, released the bolt without stripping the threads. In one instance one of the large armour bolts was sheared close to the nut and dropped into the pit. The skin to which the whole of the gear is attached being, as it were, suspended from the armour plates, and not rigidly attached to them, appears to have been capable of partially independent movement, which serves to account for the large number of bolts and rivets sheared.

The arrangement of the armour plates provided for mutual support on the principle of the arch; but, during the breaching practice, individual plates moved slightly, being lifted above the general curved surface of the cupola as well as opening out at the joint. One of the steel dove-tail wedges uniting adjoining compound plates gave way at an early period of the attack. Although this movement of the armour plates did not appear to affect their resisting power, it exerted an injurious effect on the whole system, as already pointed out.

Compound plates. The total number of hits on one compound plate was 62 direct, and 8 ricochets, which sufficed to crack it extensively, to strip the steel face off a large area, and practically to breach it. Cracks extending through the whole thickness of the face were developed at an early stage, soon after which pieces of steel began to be detached. This tendency to separation seems to indicate that the weld between the different metals was impaired by the molecular change in the material entailed by curving the plate subsequent to its construction. It is doubtful whether compound plates, although they lend themselves readily to high curvature, can undergo bending without loss of resisting power.

Wrought-iron plates.

The wrought-iron plate attacked received 15 direct hits which, beyond making shallow scoops, did not in the least affect its resisting power. No cracks were developed or welds opened.

Embrasure plate.

The embrasure plate received 7 direct hits, and with the exception of the round which struck the edge of the port, the plate sustained no damage. The beneficial effect of the swell round the ports was practically not tested.

FRENCH TURRET.

General Description.

Emplacement or pit.

The pit or emplacement (*see* Fig. 9, p. 52) consisted of two circular chambers, one above the other, and was built rather to suit the purposes of the experiment than to represent an actual structure. The walls were of brick throughout, with the exception of the upper portion supporting the glacis plate, which was built in cement concrete. The floor of the upper or gun chamber was at the natural ground level, and was supported on concrete vaulting, forming the roof of the lower or winch chamber, and containing the hydraulic pivot. Round the upper chamber, were arranged three recesses, 5 ft. broad by 5 ft. 10 ins. high; in one of these was a lift for delivering ammunition to the gun floor, worked by a small hand winch in the chamber below, communication between the two chambers being maintained by means of three speaking tubes. The lower chamber had the same diameter as the one above, and was provided with an independent entrance by a flight of steps from the ground level. This chamber contained the rotating gear, a set of ventilating fans, and the hand pump and gauge connected with the hydraulic pivot. The parapet was built up only on the side on which it was to be attacked.

Parapet.

In front of the glacis plate was a ring of concrete 9 ft. 6 ins. thick, measured from the exterior surface of the turret, with a depth of 3 ft., and an exterior slope of 35 degrees. The rest of the parapet was built up of sand, with a total thickness of about 30 ft.

No special arrangement had been made for magazine accommodation, and, as a rule, the ammunition for the day's practice was stored in the lower chamber.

The turret consisted of two armoured portions—

Turret.

(1.) The glacis plate set in concrete, and resting on a brick foundation.

(2.) The turret itself of the ordinary cylindrical form, similar to those introduced for ships during the American war, and since used generally in all navies.

Glacis plate.

1. The glacis is of cast-iron, and consists of four sectors of the section shown in Fig. 9, p. 52, having a total weight of 72 tons. These

sectors merely abut against one another, and are not bolted together or attached in any way. A channel lined with asphalte, formed in the concrete below the level of the lower surface of the glacis plate (Fig. 9, herewith), is carried completely round the emplacement, and serves to drain off any rain water. An inner curb of cast-iron, in three segments and bolted to the top of the wall of the pit, forms the path for 10 slightly coned steel rollers, on which the turret revolves, and also for six others set on vertical axes, so as to prevent horizontal movement of the turret on recoil.

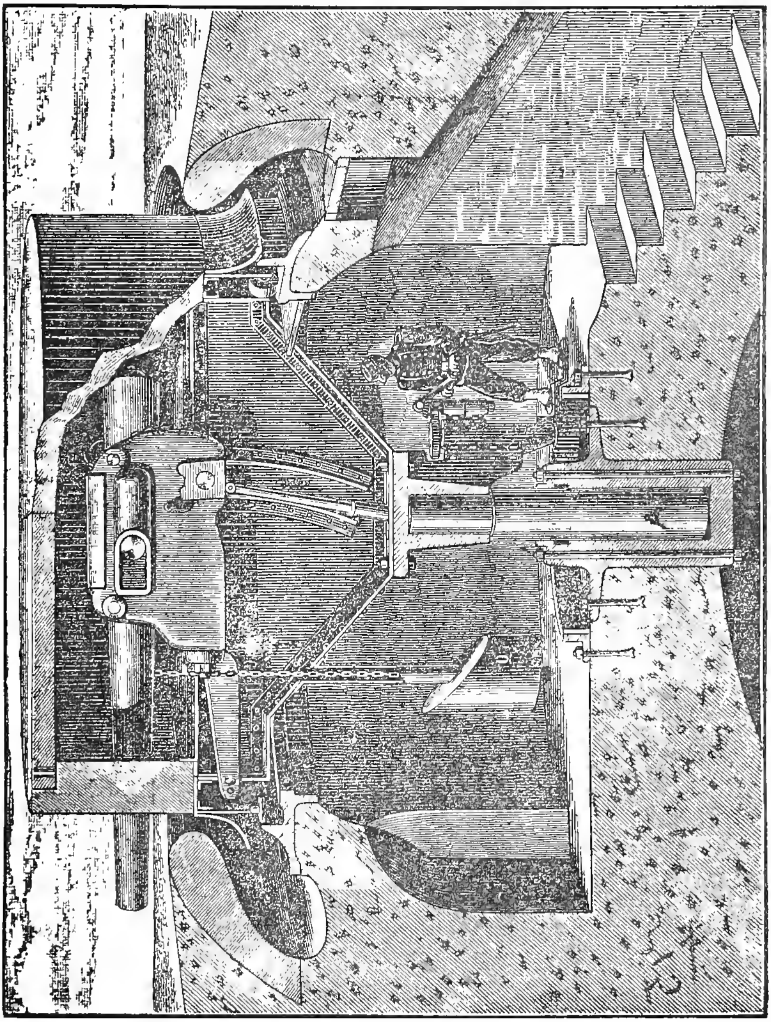
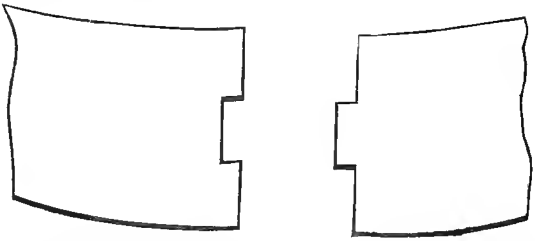


FIG 9. WROUGHT IRON TURRET DESIGNED BY MAJOR MOUGIN CONSTRUCTED AT SAINT CHAMOND

2. The curved wall of the revolving turret, exterior diameter 15 ft. 7 ins., consists of three wrought-iron plates, 18 ins. in thickness, jointed as shown in sketch (*vide* p. 53), lead being run into the joint.

Proof. The front segment is pierced for the two guns, the ports being oval; breadth, 11½ ins.; interior height, 12·56 ins.; exterior height, 17·34 ins.; distance from centre to centre, 3 ft. 2 ins. The weight of each plate is a little over 19 tons, making the total weight of the turret, less the roof plate, about 60 tons.



The turret is closed at the top by a roof plate of wrought-iron, 7·2 ins. thick, in two semi-circular portions morticed together, and weighing altogether 19½ tons, thus bringing up the total weight of the armour of the turret to nearly 80 tons. The roof plate is rebated down on to the walls, the depth of the rebate being half the depth of the latter, and secured to them by 36 – 2½-in. screw bolts with stand-up hexagonal heads and washers.

The whole of the revolving turret, as above described, rests upon a built-up annular box-girder, in which are set the axles of both horizontal and vertical rollers.

To this substructure are attached three main brackets, forming the two compartments in which the guns were mounted. These brackets, stiffened with angle-irons, as shown in Fig. 9, p. 52, are bolted down upon a heavy casting, which rests upon the shoulder of the central pivot (A), about which the turret revolves.

This pivot is of steel, 10½ ins. in diameter, and passes down into a hydraulic cylinder of cast-iron lined with steel, containing glycerine. A hand pump placed in the lower chamber was connected with this cylinder, and, by this means, the whole moveable portion of the turret can be raised by one man, when necessary, for the purpose of so adjusting the load that little or no weight rests on the rollers. These rollers are intended to serve merely as guides, keeping the structure steady on recoil. The total weight borne on the glycerine amounts to more than 100 tons.

Turning gear. The turret is rotated by a pinion engaging in a large circular toothed arc encircling the main brackets at a level a little below that of the roller path. The pinion is keyed on to a vertical shaft, the upper end of which is held in bearings bracketed out from the interior wall of the pit, while the lower end passes through the floor and gears into a double purchase winch in the chamber below. The arc is built up of several pieces bolted together, and to the main brackets, and is furnished with *lignum-vitæ* teeth. The above arrangement is not shown in the plates, which represent a slightly different design.

In the intervals formed by the three main brackets of the turret, are the gun carriages. These consist each of two parallel brackets, to the front of which is bolted a T-piece (*c*, Fig. 9, p. 52, and *c*, Fig. 10, herewith) passing into the annular box-girder which carries the conical rollers, and hinged at a point below the centre of the port, this being the point about which the gun pivots. Projections on the brackets of the carriages work in curved angle-iron guides struck with radii equal to their distance from the produced axis of the front pivot hinge. Rectangular pieces of steel fitted over the trunnions of the guns, slide in slots cut in the upper portions of the carriage brackets, allowing a recoil of 18 ins.

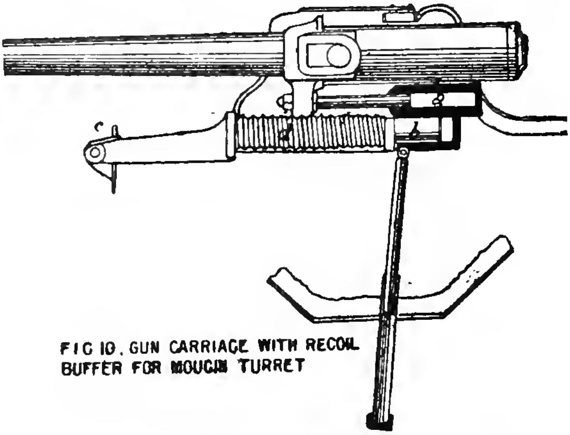


FIG 10. GUN CARRIAGE WITH RECOIL BUFFER FOR MOUGIN TURRET

Elevating gear.

On the top of the main brackets of the turret are two guide pulleys on either side of each gun, carrying chains one end of which is attached to the rear of the carriages, the other to a counterpoise (Q) hanging in front of the central pivot. The up and down movement of these counterpoise weights is steadied by hollow rods passing through them, and depending from the web plates (O), connecting the under surfaces of the main brackets. The weight of each of these counterpoises, 7,700 lbs., was such as to leave a preponderance of 1,100 lbs. to each gun. This preponderance is borne on the head of a small oscillating hydraulic ram (*b* Fig. 10, herewith), actuated by a hand pump attached to the main bracket in a convenient position.

Recoil presses.

Between the carriage brackets and immediately under the guns are small hydraulic cylinders (*a* Fig. 10, herewith), in which work steel pistons, their heads being attached to the gun. These cylinders are in hydraulic connection with larger cylinders, (*b*) placed immediately below them. The plunger areas of the two cylinders are as 1 : 2·8. To the ends of the plungers of the lower cylinders are attached cross heads, carrying two spindles on which are threaded "Belleville" cup springs. Both cylinders are filled with glycerine, which passes from one to the other, through a one-way valve, opening automatically during recoil, and permitting the fluid to pass into the lower cylinders, thus forcing out their plungers and compressing the "Belleville" springs. To run up, the valve is opened by hand, and the springs react, forcing the glycerine back into the upper cylinders. The initial load on the springs is adjusted by screws, so that they have power to run the guns out at the maximum angle of elevation of 20 degrees.

Laying. Neither guns nor turrets were fitted with sights, and there are no openings for either direct or indirect laying. Elevation is given by quadrant. Line is given in the first place by looking at the target through the gun. Round the inner surface of the cast-iron curb is fixed a gun metal ring graduated in degrees and quarters of a degree. Below this is another similar ring divided into millimetres, this last being used chiefly for giving deflection. Contact pieces, one for each gun, ride on the upper graduated arc, and can be clamped at any desired position. From the under surface of the annular box-girder depend projecting pieces, which, rotating with the turret, touch the adjustible contact pieces and complete circuits through the electric tubes by which the guns are fired. The Le Clanché firing battery is conveniently placed between the main brackets under the guns. Correction for line, after trial shots, is made by altering the position of the contact pieces on the graduated rings. To effect this, the Officer in charge has to mount a small step-ladder, and read the graduations by the light of a hand lamp.

The turret is rotated between each salvo, and the projecting pieces are hinged so as to pass over the adjustable contacts after touching them.

The inventor proposes to employ a rough method of position finding in which a "Planchette" or plane table with a squared map of the country is used. This was not tried during the experiments.

Armament. The two guns are 155^{mm} de Bange pattern, weighing nearly 3 tons; total length, 13 ft. 9 ins., with a travel of shot of about 22 calibres. Maximum charge, 9 kilos., or 19·8 lbs. Sevran-Livry powder.

	Weight. lbs.
Common (cast-iron or steel) shell	88
Steel armour piercing shell	89·8
Bursting charge of cast-iron common shell ...	3½
" " steel " ...	11½

The detachment consisted of 1 officer, 3 non-commissioned officers, and 18 men.

The operation of dismounting involves the removal of a great amount of semi-permanent gear, is lengthy and difficult, occupying at least 12 hours for each gun.

Results.

The following series (*a* to *k*) and diagrams show results of the various trials to which the French turret was subjected, arranged in chronological order.

Before commencing the regular programme, two rounds were fired from each gun, with full charges of 9 kilos. (19·8 lbs.) and "*projectiles fictives,*" weighing 51 kilos. (112 lbs.), at the maximum angle—viz., 5 degrees depression and 20 degrees elevation.

Series (*a.*)

19th December, 1885.—Trials for accuracy. 10 salvoes at a target 10 metres by 6 metres; range, 2,500 metres. In this series five salvoes were fired the previous day for sighting, the results of which were not published. The marking in this series was carried out as described in the case of the German cupola, and was, therefore, equally unsatisfactory.

Series (*b.*)

22nd December, 1885.—Trials for rapidity and accuracy. 11 trial shots, of which the last four were salvoes, were allowed before commencing this series. 25 salvoes were then fired, with the elevation and training thus obtained. Time occupied in firing 25 salvoes or 50 rounds, 1 hour 27 mins. 13 secs.

Out of the 50 rounds fired there were 44 direct hits. After the 20th salvo the target was so much damaged that the line of fire was shifted 4 metres to the left. In computing the results, these rounds have been referred to the original line. There were no missfires. The smoke hung in the turret, causing some inconvenience to the loading numbers.

Series (*c.*)

23rd December, 1885.—Additional trial for accuracy. 10 rounds were fired with German brown powder.

Series (*d.*)

24th December, 1885.—*See* remarks on the corresponding series fired from the German cupola (p. 42).

(*Series e*).

26th and 27th December, 1885.—The object of this series was to obtain 30 direct hits on the turret, at a range of 1000 metres. The turret was turned backwards and forwards through an arc of 70 degrees during the practice, with the apparent object of obtaining a distribution of the hits, such as might be expected if this system were tried under Service conditions.

The same guns were used as in the similar trial of the German cupola, and were fired singly, in pairs, and in salvoes of three, according to no apparent system. 51 rounds were fired, giving 27 direct, and three ricochet hits were obtained.

Fig. 1, p. 57, shows in development the position and appearance of the hits. The principal damage was the tearing away of a large triangular piece of metal at the top and at the junction of two plates, extending half the thickness of the wall, and laying bare the front of the roof plate. It will be seen that, owing to the movement of the turret, the hits were dispersed over an area equal to $\frac{5}{12}$ths of the whole circumference, which, no doubt, saved the plates from the severe racking they would otherwise have sustained. The maximum penetration obtained was 9¼ ins., most of the other rounds striking at angles away from the normal scooped, leaving indents of various depths. At this stage, a shell striking on the exposed junction of the

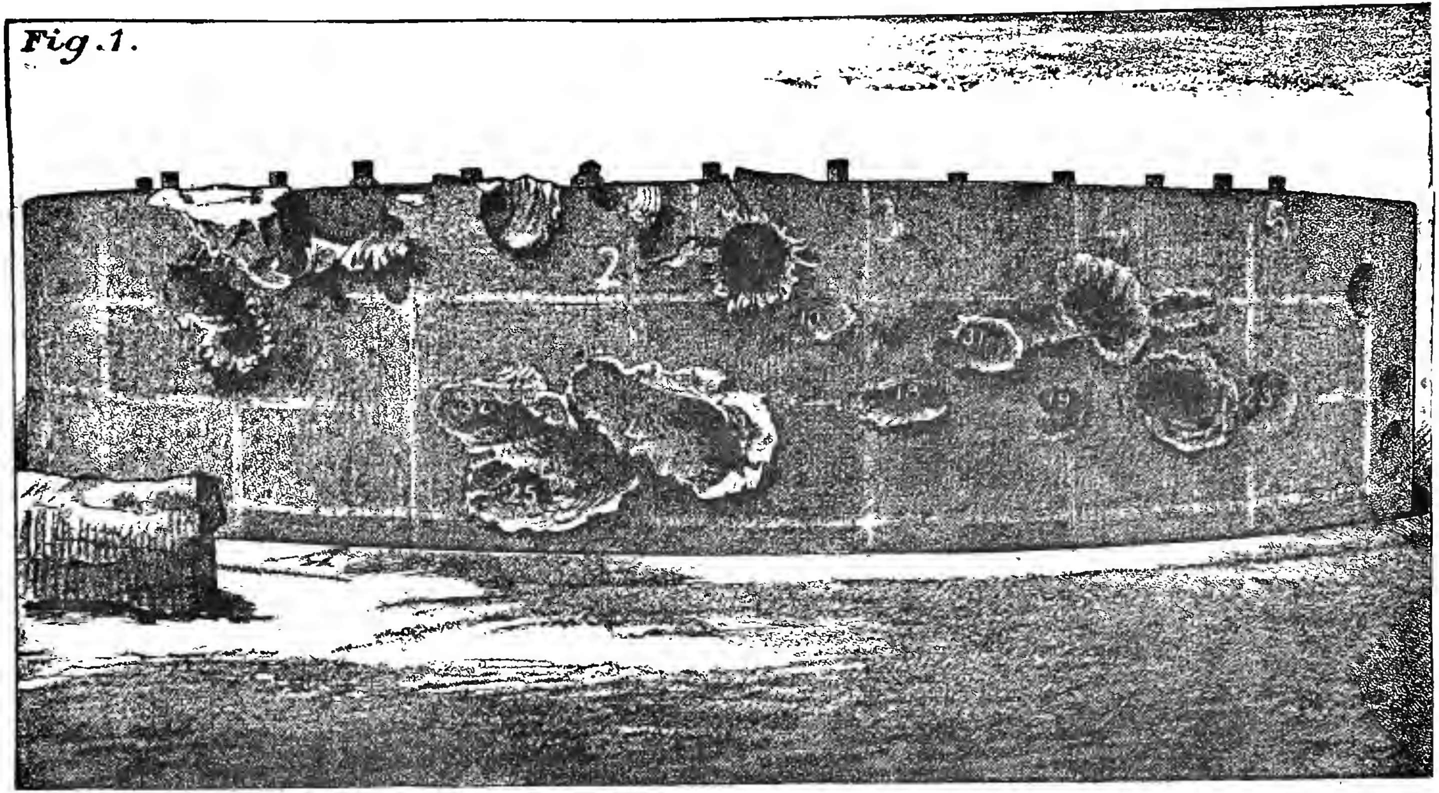


Fig. 1.

roof plate would probably have prized it up and let daylight into the turret. This state of things was practically arrived at by three rounds. It should be remembered, however, that this was a specially weak point, since it was the junction of the two halves of the roof plate as well as that of two sectors of the wall. Only one crack was developed; this ran up to the top of the plate from the round of maximum penetration. The interior of the turret and gear were unaffected.

Series (*f.*)

27*th December,* 1885.—At the conclusion of the above series, five rounds were fired from the turret to ascertain whether the gear was in working order. The practice was indifferent.

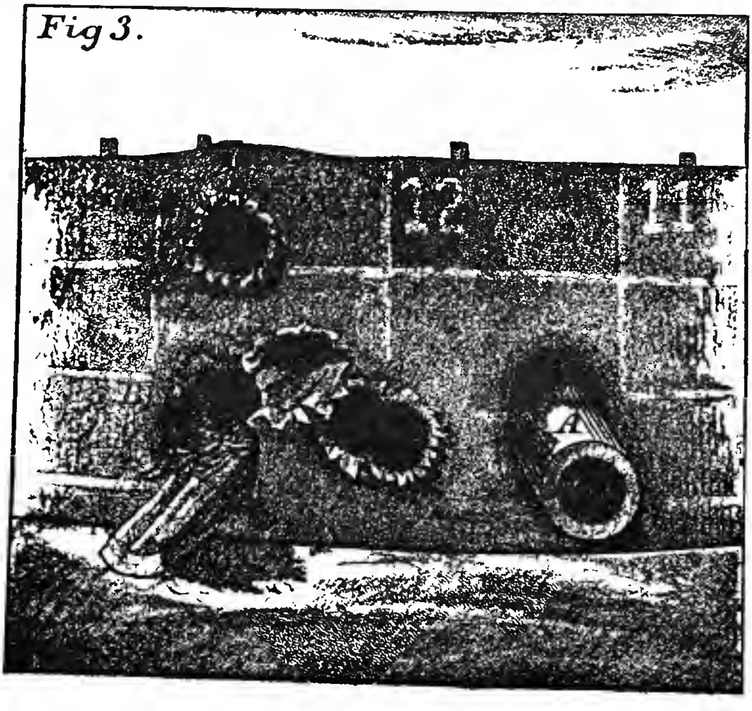
Series (*g.*)

31*st December,* 1885, *and* 1*st January,* 1886.—Mortar practice. 70 rounds were fired, and no hits on the cupola were obtained. The shooting on the whole was fair, the maximum longitudinal dispersion being 160 metres. Three shells fell on the parapet.

Series (*h.*)

5*th January,* 1886 (Fig. 3, herewith).—The guns were dismounted and replaced by wooden dummies. The attacking guns were the same as those used for Series (*h*) in the German cupola. The object was to obtain hits near the ports, the position for each hit being prescribed

Fig 3.



by the Committee. Of the four rounds fired, the first, striking close to the edge of the port, turned into it, and grazed the opposite cheek with its point, rebounding uninjured. This shell destroyed the dummy, and would have disabled a gun and its mounting. Nothing is to be learnt from the remaining three hits. All the shells rebounded whole. No damage was done to the gear.

Series (*i*).

7th January, 1886.—This series was in direct comparison with Series (*i*), German cupola, and the conditions were, therefore, apparently intended to be the same, but the attacking gun, although mounted on a built-up bank, was below the level of the glacis plate, so that all the projectiles struck at an ascending angle. In 20 rounds fired, nine direct hits and one ricochet were obtained. A number of small cracks were developed, which did not extend through the plate. This small result is attributable to the fact that, on account of the rising angle of the projectiles, and the height of the point of mean impact above the bottom of the plate, the shells striking at an average angle with the curved surface of only about 30 degrees, glanced, and did not, therefore, do their full amount of work. This explains the marked difference in these results, as compared with those obtained in the similar Series (*i*), against the German glacis plate, in which the latter was practically breached.

Series (*j*).

14th January, 1886.—In this series the practice of 26th and 27th Dec., Series (*e*), was continued with a view to forming a breach. The conditions of attack were the same, except that in this series the turret remained fixed instead of being rotated backwards and forwards through 70 degrees of arc. Further, only one gun was used, firing one nature of projectile—viz., Krupp steel armour-piercing shell. In Series (*e*) it was decided that meridian 0 should be regarded as the normal line, the area of maximum exposure to projectiles correct for line, and, therefore, striking normally, being 35 degrees on either side of this line. This meridian was, however, the joint of two wall plates, the upper angles of which had already been destroyed, laying bare the edge of the roof plate. The Committee, presumably on this ground, chose another meridian (No. 2) to the proper left, as the new medial line. This would seem, at first sight, to have been a concession to this turret, since the German turret, during its trial, had always presented the same meridian to the attacking gun. On the other hand, the French turret could have been practically breached by two or three well placed shots striking on the now open joint between the roof and wall plates, and it was perhaps desirable to lessen the chances of a premature conclusion to the trial.

17 rounds were fired on the 14th, and 27 on the 15th January.

Of the 44 rounds there were 32 direct hits (including one which grazed the roof plate, inflicting no damage), six ricochet hits, and six misses. The hits were distributed over an area of 5 ft. by 3 ft. 3 ins., grouping themselves mainly on the centre line, the shooting being excellent.

As a final result the turret was breached as soon as a group was formed near the top, but the first dangerous hit was Round 6, which struck the previously exposed junction of the roof plate, wedging it up, shearing eight bolts, and letting in daylight. The effects are shown in Figs. 2, 3, herewith, and 5 p. 61.

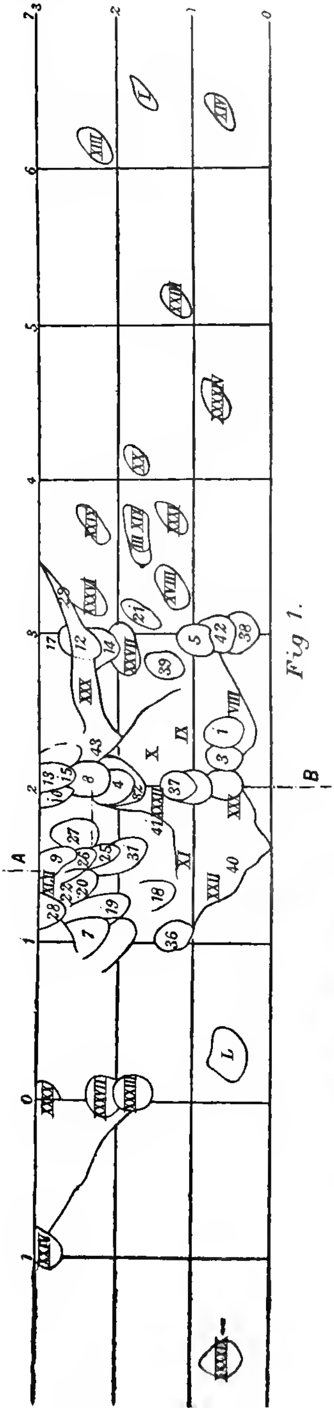


Fig 1.

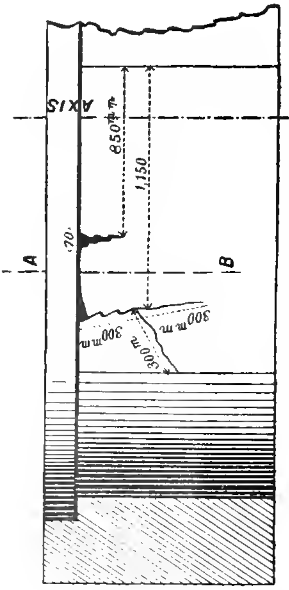


Fig 3.
Section of Wall and Interior Elevation

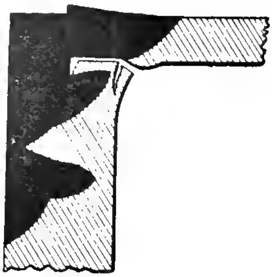


Fig 2.
Section through A.B.

The maximum penetration obtained from a direct hit was about 8 ins.; the projectile, in such cases, being thrown back without sensible deformation. In the case of glancing shots, the damage inflicted was slight, and the shell, as far as could be ascertained, invariably broke up.

An examination of the turret, at the conclusion of the series revealed no damage to interior or gear, the rotation being unimpaired.

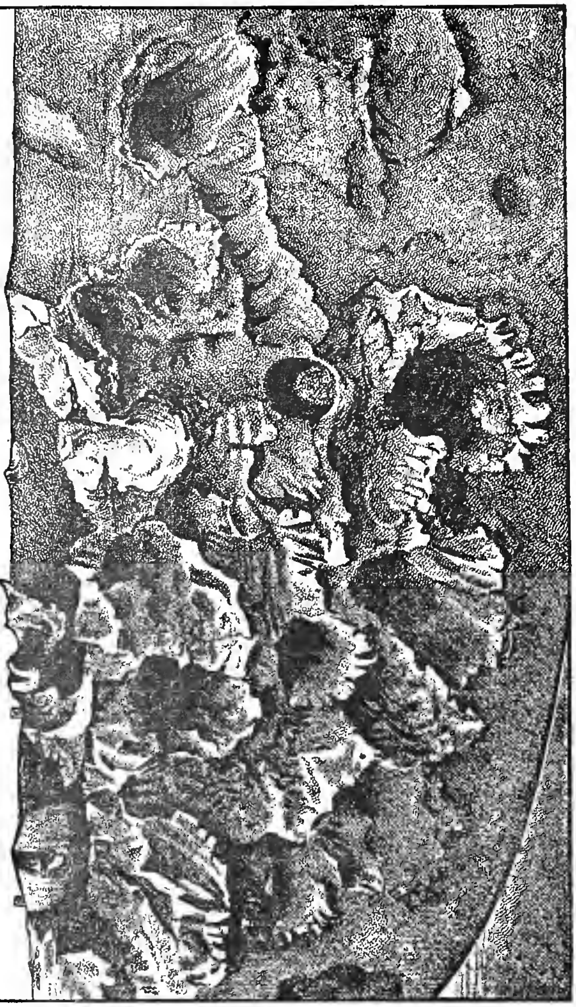


Fig 5.

Series (*k.*)

20th January, 1886.—20 salvoes were fired in this series to test the working of the turret after the breaching trial.

The mean time per salvo in this series was 3 mins. 48·8 secs., as compared with 3 mins. 38 secs. in Series (*b*).

GENERAL REMARKS.

The French turret presents the following novel features:—

1. The floating pivot.
2. The complete closing of all apertures, with the exception of the ports.
3. The absence of any inner skin, and the supporting of the side-plates by means of the roof and the base ring only.
4. The system of automatic electric firing, necessitated by (2).
5. The employment of Belleville springs to "run up" the guns after firing.

1. The floating pivot unquestionably added largely to the facility of traversing. The total load, of about 100 tons, could not have been otherwise moved without great labour. Whether and to what extent "creeping down" took place cannot be stated. The turret was throughout in the hands of the artisans specially brought from the St. Chamond Works, and they were, consequently, enabled to adjust the incidence of the load upon the trucks to any extent that might have been required.

2. The avoidance of all apertures, by which a chance splinter might enter, has been claimed as a considerable advantage for the French turret. In theory it may be desirable to avoid remote contingencies; but certain risks have to be accepted in war, and, in obviating them, practical disadvantages may be incurred. Notwithstanding that the gun chamber of the French turret had a large door always open, the accumulation of smoke was, at times, excessive. Had this door been closed, or in communication merely with a passage, it is doubtful if long continued firing would have been possible. Moreover, but for this door, the whole of the work inside the turret must have been carried on by the light of lanterns, which, considering the general inconvenience of the arrangements, would have been no easy matter. Finally, the impossibility of direct observations from the turret itself constitutes a definite disadvantage to the system. However desirable it may be, as a general rule, to regulate fire from a distant and secure observing station, it appears altogether unwise to abandon the possibility of obtaining a direct aim under the many circumstances which may arise. The theoretical invulnerability of the gun detachment may thus be too dearly purchased.

3. The absence of an interior skin was advantageous, inasmuch as there were no rivet or bolt heads to fly when the turret was struck. On the other hand, a large number of the bolts, attaching the roof to the walls, were sheared by a single hit, and a shell, striking below the exposed edge of the roof-plate, would, undoubtedly, have raised it, thus seriously affecting the stability of the whole structure.

4. It cannot be said that the principle of automatic firing was ever properly tested. There appears to be a considerable risk in thus trusting to an electric contact being completed at a precise instant.

Unless the contact pieces were always chemically clean, an uncertain delay might occur which could not be corrected for. The mere wearing of the rubbing surfaces would also be a source of inaccuracy, but would, of course, be less a matter of chance. Theoretically, provided that the pointers and arcs were correctly adjusted, the firing of the two guns should have been absolutely simultaneous, which was not always the case. Possibly, on account of the reasons above indicated, the earlier practice, Series (*a*), (*b*), and (*f*), was decidedly indifferent. In Series (*k*) better shooting was obtained, possibly because some alteration of the contact pieces had been effected. It is worthy of notice that, of the 21 salvoes in this last series, nine were fired by friction tubes, thus involving merely an optical adjustment of a pointer on the fixed horizontal arc.

5. The action of the springs in forcing the guns back into the loading position appeared to be satisfactory; but it is impossible to state whether the recoil presses necessitated special care or attention during the trials.

GENERAL CONCLUSIONS.

The value of these important and costly experiments was sensibly modified by certain of the conditions under which they were carried out.

Condition of trial.

1. The power of the guns employed in the attack fell far short of the standard of a modern heavy siege train. The Krupp 15^{cm}, and the de Bange 155^{mm}, practically 6-in. guns, fired a maximum charge of 19·8 lbs., with projectiles varying in weight from 69·3 lbs. to 90 lbs. The muzzle velocity with the armour-piercing projectiles being only about 1500 ft.-secs. As a comparison, it may be stated the 6-in. B.L. gun proposed for our heavy siege trains, fires an armour-piercing shell weighing 100 lbs., with a charge of 34 lbs. of powder, giving a muzzle velocity of 1830 ft.-secs. Thus, even discarding the probability of the employment in future sieges of jointed guns of increased power, existing armaments are far superior to the ordnance selected for these trials.

It is to be remembered that if cupolas are ever largely employed for the defence, every effort will be made to bring the heaviest siege artillery against them. It is in all respects, therefore, to be regretted that the most powerful weapons available were not employed for the attack.

2. Guns identical with those above described were mounted in the turrets. If such costly structures are to be employed at all, it is clear that the best possible guns must be mounted in them, since there is an obvious anomaly involved in expending £10,000 in mounting two weak siege guns. Even supposing that the calibre of the guns so mounted were limited to 6 ins., they would not be less powerful than our Mark IV., giving a muzzle velocity of 2050 ft.-secs., with a charge of 55 lb. brown powder and a 100 lb. shell. Whether it would be

possible to mount such a gun in either of the turrets experimented with cannot be said to be established. In the case of the German cupola it is clear that radical structural alterations might thus be entailed, since the retention of the non-recoil principle might involve a prohibitory increase of weight, strength, and cost.

With the French turret similar difficulties present themselves, though, perhaps, in a less degree.

3. A combination of a service and a manufacturers' trial, which was practically the system adopted, is in all respects unsatisfactory. The shooting was carried out under Roumanian Officers with Artillery detachments; but the artisans of the competing firms were at hand to assist in any way that might be required, and throughout the trials the turrets appeared to be in charge of their exhibitors, whose skilled workmen, living on the spot, were able to repair damage, effect adjustments, and generally make good any defects which arose during the practice. Throughout the trials the respective inventors were not only permitted to give directions and suggestions of all kinds, but to express their mutual opinions with regard to their rival's turret with perfect freedom.

4. The method of recording the results of the shooting from the turrets for accuracy left much to be desired. The telephoned reports were based on observations by an Officer, who, not having time to measure individual hits or grazes, judged them as best he could from his shelter. It was specially desirable to test the accuracy of adjustment of the guns; to ascertain if their parallelism was effected; to gauge the disturbance of one gun caused by the discharge of the other; and, in the case of the French turret, to form an estimate of the practical efficiency of the system of automatic firing. For all the above named purposes the recording of individual shots was essential, this condition cannot be said to have been complied with.

The time of year in which the experiments were carried out, and the prevalence of fog, snow and extreme cold, doubtless added much to the difficulty of the conduct of the trials.

5. In the breaching trials, the system of firing salvoes of two or three guns indiscriminately, rendered it impossible to identify the effect produced by shells of a particular class. Moreover, speaking generally, there was no opportunity for ascertaining whether particular shells broke up, or the effect on the shells themselves of impact under varying conditions. Again, little or no time was allowed for adequately recording the effect on armour plates of successive rounds. On one occasion as many as 56 such rounds were fired on a single day. Thus, the recorded results cannot be regarded as sufficiently detailed, while the trials fail to provide such data with regard to the behaviour of steel projectiles as might have been obtained.

It is now proposed to compare the merits and performances of the two turrets under separate heads.

1. Emplacement.

In this respect the German cupola has a marked advantage. In the case of the French turret, the lower chamber necessitates either a considerable excavation or a high command with its attendant disadvantages of increased visibility. The absence of any sort of recoil carriage in the German cupola leaves the gun chamber comparatively free. Thus the whole of the operations of loading, training, &c., are carried out on one floor, and therefore under the eye of one responsible officer, while the recesses provide space for the storage of a considerable quantity of ammunition. Moreover, this one chamber is, by day, well lighted from the back passage and the man-hole at the top, while the lower story of the French turret is dependent always on artificial light and ventilation.

2. Mountings.

Both systems of mounting worked well, and did not appear to be affected by the trials. The German system is open to the obvious objection that its applicability to a high velocity gun is still unproved, while there are evident difficulties to be met. The continued recoil, even of these weak guns, was sufficient to give a permanent set to the springs supporting the rear trucks. The effect of this would be to cause an error in elevation as given by arc, and practically to necessitate recourse to the clinometer. In any case, the suspending of the guns from the inner skin of the shield is open to objection. Further, the vertical steel arcs, against which the breeches of the guns rest, are supported above by the inner skin, and below by the built-up base resting on the pivot, an arrangement capable of leading to disturbance of the position of the arcs themselves relative to each other, and to the axes of the trunnions.

The employment of Belleville springs, as in the French turret, to run out the guns, would probably be applicable to more powerful guns.

The system of mounting adopted in the German turret, possessed, however, the incidental advantage that the size of the ports was reduced to a minimum, while the exposed portion of the chase of the guns was less than half that entailed by the design of the French turret.

3. Facility of Mounting and Dismounting Armament.

In the design of the German cupola the desirability for providing easy and simple means for mounting or replacing the guns has been recognized, and the arrangements have been extremely well thought out. The whole operation is quite straight forward, and can be performed by ordinary gunners. There is no doubt, that, with a certain amount of drill and practice, the time quoted might be reduced at least one half. On the other hand, in the case of the French turret, the mass of ironwork and gear which has to be removed in the process of dismounting renders the assistance of skilled artificers an absolute necessity. It was impossible to ascertain the exact number of hours expended in removing the guns from this turret, as the work was probably continued night and day, but on each occasion the operation appeared to extend over two days.

4. VENTILATION AND LIGHTING.

The ventilation of the German cupola was far superior to that of the French turret. This was mainly due to the manhole at the top of the former, by which a direct draught was promoted. In the French turret, after firing, the smoke accumulated in the upper portion of the turret to an inconvenient extent. If the gun-chamber had not opened directly into the air, this drawback would have much increased. The lower chamber of the turret was provided with a fan, apparently intended to assist ventilation; but this arrangement, if it was used, does not seem to have been successful. It is to be observed that ventilation of the lower chamber also would have to be secured if the design were applied to a work of defence.

The French turret entailed artificial lighting at all times, while the man-hole in the roof-plate of the German cupola provided ample illumination for day firing.

5. LOADING.

The large space available in the German cupola, and the fact that all the operations of loading were performed from the floor of the gun-chamber, was an undoubted advantage.

In the French turret, not only had the ammunition to be sent up by a lift from the gun floor to the platform above, but the whole arrangement was extremely cramped and inconvenient. While, in the one case, any gunners would in a short time have been able to carry out the loading operations with the necessary rapidity; in the other, careful special training would be necessary. On the other hand, it is to be observed that the German system of mounting practically limits the choice of breech action to a side wedge of the Krupp type, and precludes the employment of a breech-screw.

6. ELEVATION.

The guns in both cupola and turret being counterpoised, elevation was given without difficulty. In the German cupola, the guns being overbalanced, the breeches were hauled down to elevate. In the French turret, there was a small preponderance, and the breeches were raised by a little ram, actuated by a pump. It would be interesting to know whether this ram was able to maintain the breech at a constant elevation, or whether any slight variation took place. No experiments were made with a view of testing this point. In the German cupola, the breeches were clamped as soon as the required elevation had been obtained.

7. TRAVERSING.

The French turret appeared to traverse more easily and smoothly than the German cupola, in spite of its far greater weight. The former being intended always to make a complete revolution between each salvo, the designers had been led to adopt the floating pivot, to which the comparative ease of traversing was mainly due. The greater finish of manufacture of the French turret was not without influence however; while the adoption of wooden teeth in the main gearing was doubtless advantageous. These features are of course equally applicable to the German cupola. The latter possessed the advantage that the traversing, being carried on in the gun chamber, could be directed by the officers in charge by signal, without the necessity for having recourse to a speaking tube.

The horizontal arc of the German cupola could be read without difficulty from the floor of the gun chamber. In the French turret it was necessary to mount steps and to use a hand lantern. On the other hand, the arrangement of the pointer in the former case was decidedly objectionable; since, although placed at a distance so great as to involve parallax, it nevertheless struck the arc violently during the oscillations of the cupola on recoil.

8. Sighting.

The power of laying by sight appears to be a decided advantage in favour of the German cupola. Not only can direct laying be employed which, in the case of a moving object, would be of the highest importance, but back laying by means of the hole in the rear armour plate can be utilized.

In the French turret, unless a system of position finding is applied, it is necessary in the first instance to lay the guns through the bore by means of a sighting tube or cylinder. Thus, if comparative trials at a moving target had been carried out, or even practice against dispersed targets, the German cupola might have been expected to show a marked superiority. It is to be observed, also, that this cupola lends itself equally well to the employment of a position-finding system.

The complete closing in of the French cupola, and its absolute dependence under all circumstances on information supplied from without, is a condition which is likely to recommend itself only to the pure theorist. The chance of a shrapnel ball or machine gun bullet finding its way into the turret through the opening in a conning tower may well be accepted, in consideration of the advantage of allowing the Commanding Officer of the turret an occasional view of the distant terrain, instead of rendering him completely dependent on an observer who may be killed, or a system of communication which may break down. Such a break down would probably result in the continuation of a useless fire, and a waste of ammunition.

9. Accuracy of Fire.

It is greatly to be regretted that no series were fired with the object of obtaining comparative range and accuracy groups. The results of each round, or salvo, were usually telephoned back to the firing point, and as these results could not in many cases be other than approximate, the practice does not afford a satisfactory comparative test of the shooting capacity of the cupola and turret. Again, for the reasons stated on p. 49, the principle adopted in the German cupola appears to demand electric salvo firing as a condition of satisfactory practice, and the fact that the salvoes were all fired by word of command, resulting in many cases in a distinct interval between the rounds, doubtless told against the accuracy of the fire from the cupola, while precluding the formation of a just estimate of its capabilities. Generally speaking, the shooting was indifferent, which must be partly attributed to the conditions of the mounting, and also to the changes in direction and elevation being made on information sufficiently accurate. On the other hand, the practice in Series (*k*) from the French turret, during which it is believed that no results were telephoned, and no corrections in elevation or direction were made, was decidedly better. In neither cases is there any reason to suppose that the shooting was affected by the battering the cupola and turret received in Series (*e*) and (*j*).

In the case of the French turret, the gun mounting being entirely independent of the shield, there appears to be no reason to expect any inaccuracy from this cause. In the German cupola, however, it is evident that errors might arise from a distortion of the skin, produced by movement of the supported armour plates.

The efficiency of the automatic system of firing, which forms one of the special features of the turret, cannot be said to have been properly tested. Judged by Series (*k*), it appears to have acted fairly; but more extended trials would evidently be necessary to dispose of the objections pointed out. On the other hand, the arrangements for laying the German cupola for direction by arc and pointer were rough and unsatisfactory.

10. RATE OF FIRE.

A comparison of the two Series (*b*) shows that the German cupola fired 25 salvoes in 2 hrs. 27 mins. 20 secs., giving a mean time per salvo of 5 mins. 54 secs.; while the French turret required only 1 hr. 27 mins. 13 secs., or an average of 3 mins. 38 secs.

This comparison is, however, scarcely just to the German cupola, which was made to perform a whole revolution after every salvo, merely because the French turret had been specially designed for this purpose, and could be loaded during rotation. This was claimed as an advantage by the inventors, since the guns were thus rendered invisible, and practically invulnerable to the attack during a portion of the period of rotation. It may well be questioned whether this advantage has any real existence. When facing the attacking battery the guns present a small mark; when nearly at right angles to the line of the enemy's fire they offer a broadside target, which on account of the protrusion of the French guns is considerable. Under service conditions, the fire of the attack from the first artillery position at least, would not be so extremely accurate that each round would strike close to the ports, if the turret were not rotated. Hence it is doubtful whether the chances of a hit on the muzzle or chase are not rather enhanced by turning them round and presenting a broadside view twice after each salvo. In any case, the rate of fire is much reduced by the operation, while a great strain is thrown on the traversing numbers, who would have to be relieved at short intervals.

In Series (*k*), fired after the breaching trials, the average time per salvo in the German cupola was 6 mins. 35·8 secs., while in the French turret it was 3 mins. 48·38 secs. Thus the increase in the averages was 41·8 secs. and 10·38 secs., respectively.

No opportunity was afforded to the German cupola of proving its rate of fire without turning; but in Series (*b*) the mean time per salvo for loading and laying was 1 min. 29 secs., which must approximately represent the maximum. It is evident that similar guns on siege mountings are capable of a greater speed of fire, and the loss of time is due to the inconvenience of performing the loading operations in the cupola, and also to the greater weight to be traversed.

The two Series (*d*), apparently intended to test the performances of the cupola and turret against a moving target, obviously afford no data, comparative or otherwise, which can be regarded as of value.

11. Resistance of Shields.

The German cupola received in all 85 direct and 12 ricochet hits. As will be seen from Figs. 4, 5 and 6, pp. 46 and 47, by far the greater proportion fell upon a single compound plate, and were grouped near its proper left edge. The general result was the stripping off of the steel face over an area of about 10 square feet. No actual breach was effected, but the left hand top corner of the plate attacked was detached and remained merely supported in position on the inner skin; a single shell falling on this part of the shield would have penetrated. When it is remembered that this one plate received 51 hits, including ricochets, the resisting power must be classed as high. This excellent result is evidently due to the flat curvature of the design, and not to the material. It was shown that the steel face was first cracked up, and eventually detached under successive blows, proving that the weld between the two metals was imperfect. This was probably due to the re-heating and bending of the plates after manufacture. The wrought-iron plate was unfortunately not subjected to a comparative test, as it only received 15 hits, well distributed. This plate, however, exhibited no signs of cracking, and individual hits merely made scoops in the metal varying from 0·4 in. to 1·12 in. in depth, the shells in most cases breaking up. There seems to be no doubt that a curved wrought-iron plate, even of this small thickness (8 ins.), is capable of successfully resisting a large number of hits, since it would appear extremely difficult to obtain any cumulative effect. It was intended to fire a series of flat-headed projectiles against the curved shield, as it was considered that better results would thus be obtained. There is obviously no reason to expect that this would be the case, since experiments at Shoeburyness have proved conclusively the superiority of ogival shot under all circumstances.

The armour of the French turret received altogether 63 direct and 9 ricochet hits, of which the greater number were grouped over an area of 21 square feet. Projectiles striking normally, penetrated to a maximum depth of about 9 ins., the steel armour-piercing shells usually rebounding uninjured. When any hit took effect within about 18 ins. of the edge of the plate, cracks were generally developed extending to that edge. The tendency to form vertical cracks was specially noticeable. This weakness was probably due to the initial strain induced on the outer surface by bending the plate. An examination of the fracture showed a large crystallization towards the face of the plate. In the case of oblique impact, the projectiles generally broke up, forming irregular cuts. In some instances, however, a sidelong print of the projectile was formed in the soft metal. The turning of the turret during the breaching practice in Series (*e*) rendered it impossible to estimate the angle of impact of individual rounds. The principal damage was caused by a number of shells striking near the top of the wall, laying bare the junction with the roof plate, and finally prizing up the latter and shearing a large number of the attaching bolts. At the conclusion of the breaching practice, therefore, a projectile striking the exposed lower edge of the roof plate would probably have lifted it bodily, while a portion of plate near the top of the wall was so weakened that it could easily have been penetrated.

It will be seen, therefore, that these results bring out the great advantage of the spherical model. Although a direct comparison is hardly possible, there is every reason to suppose that the 8-in. wrought-iron plates of the German cupola possessed a power of resistance fully equal to that of 18-in. wall of the French turret.

If a more powerful gun had been employed in the attack, the French turret would have suffered in a relatively higher degree.

12. Damage to Interior.

The number of rivets and small bolts detached during the attack on the German cupola was considerable. Although they appeared to have merely fallen without force, it is evident that this liability must be guarded against in a fighting machine. The threads of the large armour bolts were so fine that one of them was actually shaken out of the shield, apparently uninjured. This ought not to have been possible.

The employment of a rope mantlet, or of an independent inner skin, would prevent the fall of rivets, &c. It would probably be possible, however, to cushion the shock transmitted from the armour plates to the skin, so as to obviate this great disadvantage.

The breaking of a pinion belonging to the traversing gear, appears of less importance. It is clear that this pinion should never have been made of cast-iron.

The absence of an interior skin in the French turret proved a great advantage. There were no bolts or rivets which could, under any circumstances, have fallen, and the damage was nil.

13. Glacis Plate.

The glacis plate trials, Series (*i*), do not lend themselves to a satisfactory comparison. On account of the considerably greater height of the French turret, with respect to the attacking gun, its glacis ring could not be hit at so great an angle as that of the cupola. The flatter curvature of the French section told further in its favour. Six direct hits were obtained on the German glacis plate, forming a group near the bottom edge, and breaking off a large fragment, which, however, was not detached. The French glacis plate received nine hits, forming a dispersed group about half-way up. Thus all the hits were very oblique, and, though numerous hair cracks were developed, no real damage was effected.

The attack was carried out at 54·6 yards range, and in the case of the German cupola 16 rounds were fired before the glacis plate could be reached, although the spade was freely used meanwhile in clearing away the sand and concrete débris. It is sufficiently evident that, even at 1,000 yards, it would be perfectly useless to attack either glacis with such guns as were employed in these experiments. It appears doubtful, indeed, whether a cast-iron glacis ring of this form could be successfully attacked by any gun or howitzer which could be put into the trenches.

14. VISIBILITY.

The German cupola possessed a marked superiority in the smaller and less conspicuous target offered to the attack. The result of this was that in Series (*e*), 85 rounds were fired at the cupola in order to obtain 30 direct hits; while in the case of the turret 27 hits were obtained in 50 rounds. Taking Series (*e*) and (*f*) together the comparison is 58 hits in 137 rounds, against 59 hits in 94 rounds. In other words, at a range of 1,093 yards it required about one and a half times the number of rounds to obtain the same number of hits on the cupola as on the turret.

The low, flat, umbrella-shaped cupola could, if properly coloured and with a suitable back ground, be rendered almost invisible.

15. EMBRASURES.

The attack on the embrasure plates affords no comparative data. Twelve rounds were fired against the German cupola, and only four against the French turret. As soon as a hit was obtained on the edge of the port, the gun in each case must be considered to have been destroyed.

In the case of the German cupola, however, the steel casting, supporting the right front trunnion was also broken, but could have been replaced without difficulty. To this damage the French turret was not liable; but, on the other hand, the main danger arising from a hit at the port is evidently the destruction of the gun.

GENERAL REMARKS.

From what has been said above, it will be evident that both the structures under experiment fall far short of the ideal land service cupola. The practical value of the trials was greatly reduced by the weakness of the guns employed. If turrets of any form are to be adopted in the main armament of land works, it is clear that much heavier guns must be put into them. The great expense involved could not otherwise be justified. The cost of the French turret alone was about £10,000, exclusive of its armament, and for this sum about six overbank guns of greater power could be provided. It may fairly be questioned whether the latter would not be a wiser mode of expending such an amount.

Again, if cupolas of any form come into general use, the heaviest possible siege guns will be brought against them. The Russians already have a screw gun of 8-in. calibre, and the development of this system promises to confer increased power on the attack, which is limited only by the weight of the heaviest portion. In any case, the Krupp and de Bange guns employed at Bucharest do not even reach the standard of existing siege ordnance. For these reasons, any deductions which can be made from the trials in question are necessarily subject to qualification.

Summing up; the main advantage of the German cupola was its form, and the main defect the detachment of the interior bolts and rivets. In the case of the French turret, the principal merits were the floating pivot and the absence of an inner skin; while the chief drawbacks were the want of any means of direct laying, the bad ventilation, the complication and general inconvenience of the interior, and the greater cost of the emplacement.

By combining the best features of the two designs it is possible that a satisfactory military machine could be arrived at. A cupola with a wrought-iron umbrella-shaped shield, supported on a floating pivot, and armed with guns provided with a recoil mounting and port pivoting might meet all requirements. The turtle-backed shield is the practical recognition of an important principle, and constitutes a decided step in advance. One of the most important facts brought out at Bucharest was the great resistance of a comparatively thin wrought-iron plate of this flat curvature. It is significant that the designer of the French turret has since proposed a structure in which the German model is copied bodily as to form.

The general question of the necessity for the adoption of cupolas for land defence receives no new light from the Bucharest trials. The armour in both cases received a number of blows, probably representing a siege of many months duration. But, on the other hand, it is evident that had the guns been turned towards the attack they would have been many times disabled. Against the direct frontal fire of high-velocity guns, the cupola appears to afford no increase of protection commensurate with its cost. Against curved fire and flank fire, however, the gain of security is considerable.

If a horizontal shield, capable of providing protection against the projectiles of the heaviest siege howitzers, can be provided for the pits of disappearing guns, this system would seem to be preferable to any land service cupola at present devised. The main point of weakness, the opening through which the gun is raised and lowered, is perhaps more than counterbalanced by the absence of a well-defined and always visible target.

SUPPLEMENT TO CHAPTER III.

Improved Mougin and Proposed Disappearing French Turret.

Le Genie Civil, of January 15th, 1887, describes a new disappearing turret to be tried shortly at Chalons. The writer (Claude Manceau) observes that certain inconveniences are inseparable from the dome which Major Schumann employs. It is suggested that the joints of the Schumann dome offer weak places, that the bolts are liable, both from shock of discharge and of impact, to fly and cause much injury to the detachment, and that it is impossible to predict what dislocation might be caused by the blow of even a single 21 c.m. (8·27-in.) projectile falling vertically on the cupola dome, seeing that at Bucharest the vertical fire failed to strike either cupola. It is considered that Major Mougin, in the mushroom-shaped dome which he has now adopted, has remedied some of the faults of the Schumann construction. Dislocation is rendered less liable to occur because the dome is jointed in two parallel lines, shown in Fig. 2, p. 74, which is thought much better than the radial form of division, which, it is urged, leaves each shield overhanging and dependent for its stability on the support of the contiguous sections. The Mougin cupola will then, it is remarked, resemble that of Schumann in general appearance, but it will differ from it in its principles of construction, seeing that the guns of the latter are attached to their cupola, causing inaccuracy in fire as well as other evils. It is further observed that at Spezia, in 1886, the Grüson turret shield threw off the Krupp forged steel projectiles of proved excellent quality, breaking them up in small fragments. This, it is considered, is in a great measure to be attributed to the profile of the shield, against which the projectiles must strike at an angle more oblique than 45 degs.; but the extreme hardness of the metal is also noticed. The effect of projectiles with flat, or rather slightly concave cupped points is discussed. These projectiles, advocated by Whitworth and Krupp, have cut like a chipping tool into armour at oblique angles, the case in view being probably that at Buckau, when Ternitz projectiles bit into the surface of a Grüson cupola. It is suggested that an attack with cupped-out projectiles would prepare the way for sharp pointed projectiles to enter. At angles over 25 degs., it was generally found at Gâvre—as in England at angles over the glancing angle—that a given vertical height received the same protection from a given weight of metal, whether the wall was at an inclination or placed vertically.

The main disadvantage of the cylindrical form then lies in the vulnerability of its sharp top edge, and in the distinctness with which

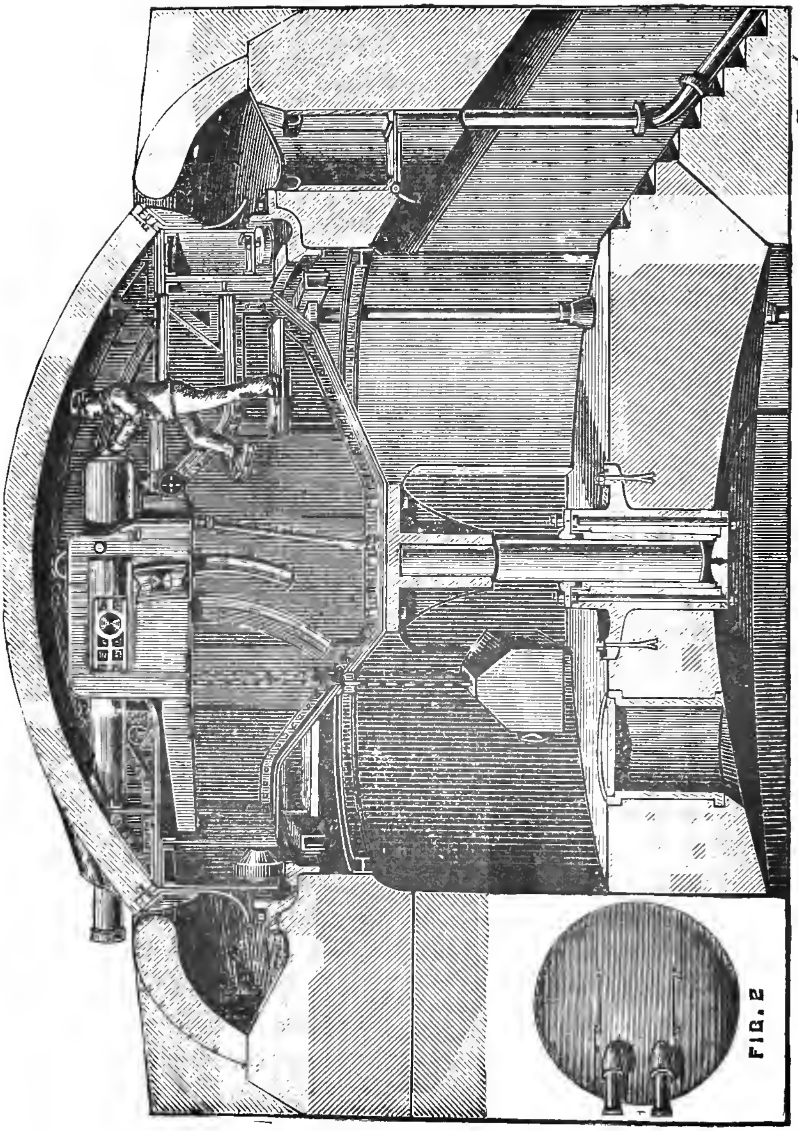


FIG. 4

FIG. 2

so defined a form can be seen. At Cotroceni the latter evil was increased by the fact that the French turret stood on higher ground than the German one—a fact, we may observe by the way, which gave it a great advantage when its glacis plate—*avant cuirasse,* was attacked. The French turret also was painted black, and the German one grey.

M. Manceau concludes that the Bucharest experiments showed that no turret could resist constant artillery fire for a very long period, consequently, that it is most desirable to put it under cover, if possible, whenever it is not actually firing. This is what has been done in the design shown in Fig. 1, p. 76. The cylindrical form has been adopted; the roof is made in one piece. There is little to fear from vertical fire, and the edge of the plate is fitted to the vertical wall in the manner shown in Fig. 1, p. 76, which, it is thought, favours the throwing off of the projectiles and dispenses with vertical armour bolts.

As to metal, it is thought that the experiments of Cotroceni did not conclusively establish the relative resisting powers of steel-faced and wrought-iron shields. On the whole, however, it has been decided to adopt steel-faced plates in the design before us—the machinery for effecting the union of the face and foundation plates being of such power that a high degree of perfection in the weld may be expected.

The interior diameter of the turret will be 4·6 metres (15 ft.). The vertical wall is 1·2 metres high (3 ft. 11¼ in.), consisting of three plates of 50 centimetres (19·69 in.), which are fitted together by tongues and grooves.

The roof plates resting on the wall, as above described, are 20 centimetres (7·87 in.) thick. The whole armoured structure rests on a wrought-iron structure and trunk, 5 metres in height, comprising two cylindrical portions of 1 and 2 metres, and a conical portion (*see* Fig. 1, p. 76). The cylindrical parts slide, during the vertical movement of the turret, in two guiding rings; these keep the turret in the vertical position.

The base is supported on the piston of a hydraulic press, 45 centimetres (17·72 in.) in diameter, which constitutes the pivot of the turret which moves on it. The centre of gravity falls well over the pivot, and rollers can be dispensed with. The piston is 1·5 metres (4 ft. 11 ins.) long, the movement being 1 metre only, half a metre is always left in bearing. It is pierced from end to end for the passage of the liquid used in the press.

The total weight is 150 tonnes (147·63 tons). The plunger being 45 centimetres (17·72 in.) in diameter, a pressure of 100 atmosphere (0·66 tons) will support the whole structure.

The original element in the new design, which enables so large a mass to rise quickly, consists in the counterweight of an accumulator, of which the cylinder is in communication with the turret pivot press. The plunger of the accumulator is double the size of that of the pivot, consequently 7·5 tonnes (7·38 tons) is sufficient for the counterweight.

To destroy the equilibrium, water is admitted in the annular cavity

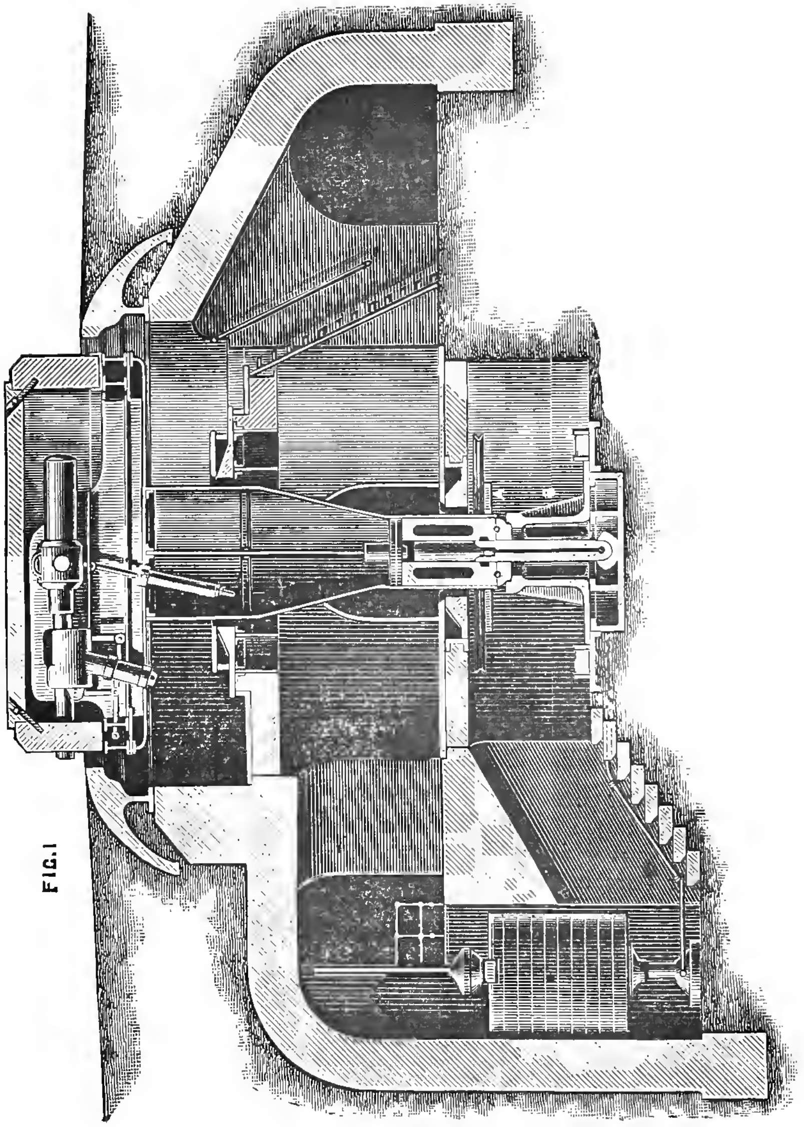


FIG. 1

round the piston. The differential effect thus produced provides for the vertical movement of the turret, which can be effected as quickly as the rotation, seeing that in each case it is a question only of overcoming inertia. Rotation is effected by means of the horizontal wheel at the base of the turret (*see* A, Fig. 1, p. 76), by chain gear, or, better still, by hydraulic gear.

The two subterranean chambers facilitate the working of the gun by keeping the chamber from becoming crowded. The ammunition is brought up to the level of the breech of the gun by a lift from beneath. The carriage is entirely separate from the shield. The port is reduced to a minimum size by a jointed frame forming the system of parallel bars shown in Fig. 3. The gun and moving parts of the carriage are supported on an oscillating hydraulic press (*see* Fig. 3).

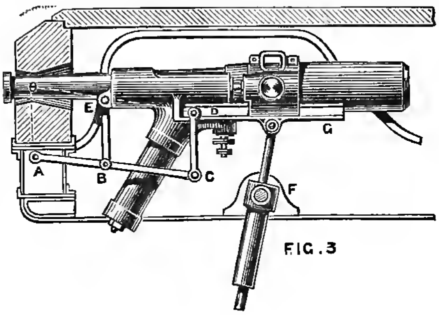


FIG. 3

The recoil is met at the trunnions (as in some of Rendel's designs), so that there is no disturbing couple generated by the shock of discharge,

The muzzle of the gun projects so little that disappearance is not interfered with and can be effected in all positions. When elevated for a long period the turret receives additional support brought under the base by hydraulic power (B Fig. 1, p. 76). It then rotates on a ring of balls.

Fig. 4, p. 74, shows the new cupola adoped by Major Mougin. Little description is necessary, because the interior fittings are practically the same as those employed by him in his cylindrical turret at Bucharest. He has adopted the German mushroom form of dome, but, undoubtedly, as above noticed, the fact that his gun is separate from the shield constitutes a fundamental difference. In this, Major Mougin has a great advantage ; but it is difficult to see why Schumann might not employ very much the same thing—Krupp has had recoil arrangements closely resembling this one. Altogether, however, this modified Mougin turret is excellent.

The disappearing turret must be commended for ingenuity and neatness, but there are one or two points that seem weak or doubtful. The turret is in its weakest position when in action, and it is questionable whether it is not a little top-heavy and delicate. Any contorting force would act with a powerful leverage on the piston. Another objection appears to be the curtailment of the length of the piece.

Further, it must be borne in mind that the protection due to disappearance becomes less than might at first be supposed when the turret is in action. In a siege the firing is very systematic, and a besieger's guns would be pointed and waiting for the appearance of the turret. The latter could not move up and down sufficiently quickly to make feints and escape any fire. Generally speaking, the turret guns and its adversary's would be loading during the same periods, and unless the rates of loading differed much, the fire of the attack might be interrupted only to a very limited extent. This, however, must be decided by trial. Disappearing guns in pits are admirable, but in a siege there may occur spots too hot for an open pit to be tenable by a detachment, when a disappearing turret, or a plate covered pit with a gun coming up through an opening might be very valuable. As to vertical fire on the roof of either turret, the effect would be *nil.* Our ships with 3-in. decks are in a very different position as to protection. A solid 7-in. plate is about five times as strong as a 3-in. one, the resistance being proportional to the squares of the thicknesses.

Incidentally, the adoption of steel-faced armour for the new turret is worthy of remark. It will be found to be suggested in this work that if through fracture is to be avoided, steel-faced iron armour or plates compounded of hard and soft steel will, in the long run, be found better than solid steel. Here is a case in point; the plates of a turret of this kind constitute the structure itself, and through fracture would be ruinous. It appears that under these conditions the French authorities, who surely have the greatest experience with steel, do not employ even the softest steel, nor do they, as we might suppose, continue to use wrought-iron—although all the turret iron armour behaved very well at Bucharest; but they go out of their way to adopt steel-faced plates. This, of course, is only experimental, but still the selection for trial shows their present opinion. The French are not likely to be disappointed in their steel. It has performed great things. No wrought-iron—not speaking of compound plates—could have behaved as well as the steel plate at Spezia in 1884. But any adoption of steel must probably be accompanied by the acceptance of through fracture and reliance on numerous bolts to hold the shield together. Sheffield makers ought to be encouraged by the preference of steel-faced armour for the new turret.

CHAPTER IV.

ARMOURED STRUCTURES.—FORTS.

ARMOUR has been applied by our English Engineers to coast forts only, though in some cases it may be specially valuable inland. Coast forts would generally be assailed by heavier guns than would be employed in a siege. On the other hand, an armoured fort inland would be liable to be attacked more persistently and systematically than could well happen in the case of a coast fort. Thus, it naturally follows that wrought-iron is admirably suited for inland works,[1] while chilled-iron has been chiefly employed for coast defences.[2]

Under the head of chilled-iron, the principal classes of cupolas and batteries of Grüson's armour have been briefly described (*vide* p. 1, Part II.), and it has been pointed out that England differs from other powers in having her coast forts protected with wrought-iron armour, which, although it may be in a measure re-inforced or superseded by compound armour, will for a long time to come form the main fabric of our shields. A brief description of the classes of the structures used on the coast of England, together with what has been already given on Grüson's chilled-iron shields, will be sufficient for the purpose in hand. The following is taken from a paper read by General Inglis at the Royal Artillery Institution, which dealt much more fully with the subject :—[3]

The armour takes four forms.—(1.) *Casemate shields built in masonry.* (2.) *Shields in masonry, with guns on turntables.* (3.) *Iron batteries.*[4] (4.) *Turret.*

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[1] *Vide* Bucharest trials.

[2] The Alpine shields, noticed in p. 5, Part II., are perhaps almost the only case of chilled-iron shields adopted for inland defence. The peculiar action of wrought-iron and its value against continued fire, as compared with chilled-iron, is illustrated in Krupp's Meppen trials of 1879, *vide* p. 96, Part I.

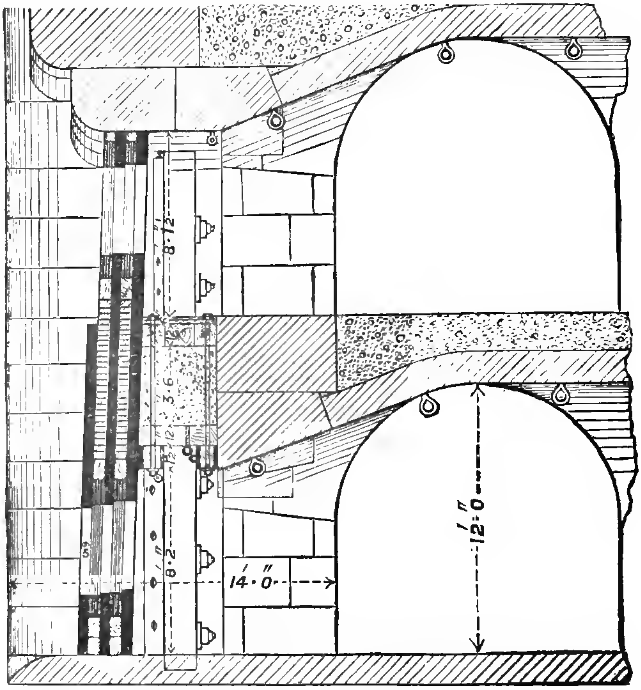
[3] Read at R. A. Institution, April 29, 1880.—*Vide Engineer,* May 6, 1881, p. 326.

[4] That is, a battery whose entire walls are iron-armoured.

Casemate shields.

Casemate shields in masonry.—Fig. 1 gives a section of Picklecombe and Garrison Point forts as a specimen of two-tier shield fixed in masonry, showing however a comparatively weak sample. At Garrison Point, Sheerness, the 38-ton guns have three 10-inch plates in front of them, instead of three 5-inch. Speaking generally, the shields are built into the masonry in the following way;—A strong frame of $\frac{3}{4}$-in. plate, and 6-in. × 6-in. angle-irons is constructed in the masonry, being built in, and attached by bolts, dove-tailed pieces, &c. On this is built the armour, generally on the plate-upon-plate system. Between the inner plate and the shield frame there is an inch interval usually filled with wood.[1] The drawing explains itself.

FIG. 1.



Shields in masonry with guns on turn-tables.

Fig. 2, p. 81, shows a specimen of turntable battery (Class 2), such as that at Helen's Fort, Portsmouth, Malta and Gibraltar. They occur where a lateral fire extending through about 120° is required. Each gun has two ports, and moves to either by means of the turntable. Here again the example taken is a weak one of its class, although the structure is strengthened by intermediate layers at the ports, and heavy iron-cased concrete supports between the ports. Three 6-in. or two 9-in. plates are used in some places.

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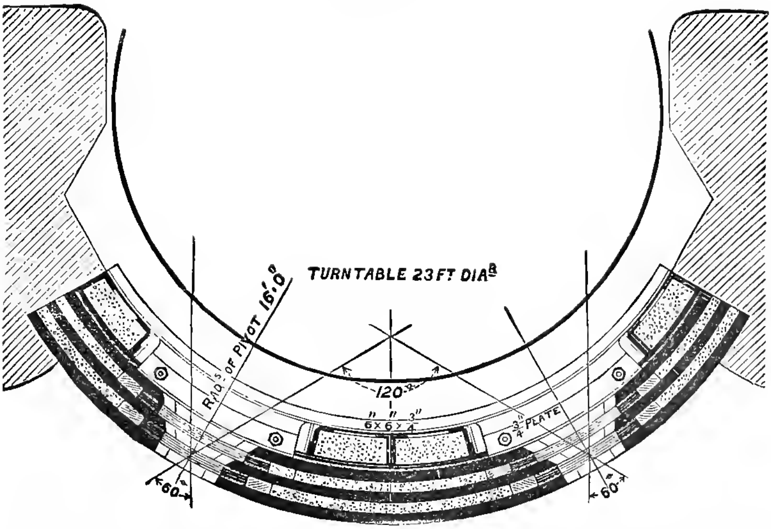
[1] Each thickness of armour is bolted to the one next behind it, and the rear plate to the shield frame.

Fig. 2.



Shields and turntable.

Omitting Plymouth Breakwater, which is a stronger but perhaps less interesting structure, (Class 3) may next be taken. *Iron batteries,* of which the two great forts of Spithead, *Horse Sands* and *No Man's Land,* are good specimens (*vide* 3). Here again may be seen the

Iron batteries.

Fig. 3.

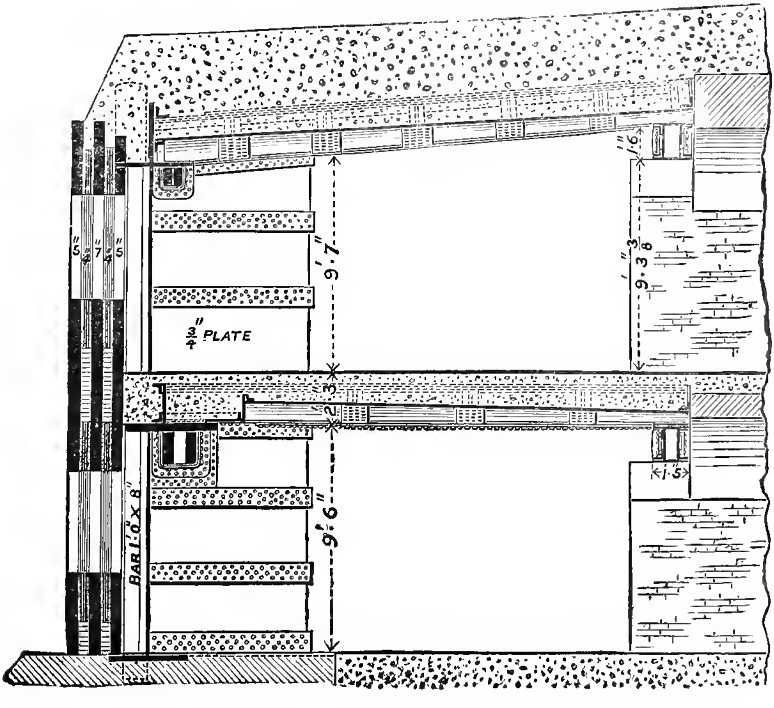
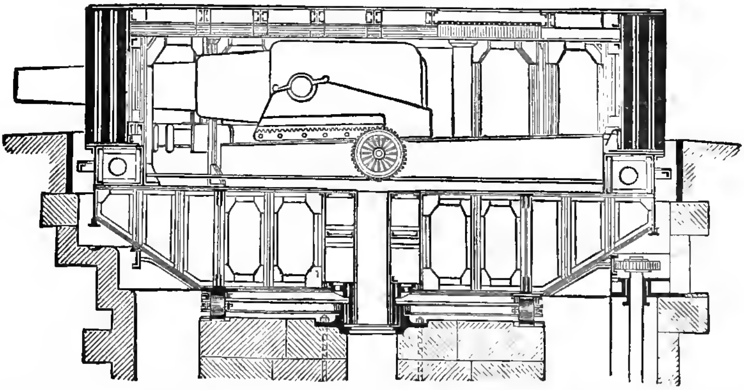


plate-upon-plate armour, coupled with the principle of keeping the armour separate from the floor structure, so that any contortion of the armour may not affect the racers or structural parts on which the working of the guns vitally depends. There are armour bar supports about 10 ins. × 5 ins. × 4 ins., the greatest section of each being placed normally or radially to the wall, about four inches apart, extending from the lower floor to the roof. The pier cases are filled with Portland cement concrete. The safe load of the upper gun floor and of the roof is equal to a mass of concrete laid 10 feet thick over it, or half a ton on every square foot. The middle plates of the armour stand on end, being 22 ft. 6 ins. long, extending from base to roof. Concrete is used between the plates except at the port frames, where wood is employed. It may be seen that here again it would be easy to add outside rings of armour and masonry to correspond, for which work, express provision is made. The weight of iron work on these forts is as follows:—skeleton per gun, 50 tons, total 2450 tons: armour wall per gun, 75 tons, total 3764 tons; total weight, 6214 tons. Each sea fort at Spithead, Spitbank and Plymouth is prepared for the addition hereafter of turrets on its roof, each to carry two of the heaviest ordnance. The Spithead forts can carry five turrets each; the others two each. Rope mantlets soaked in chloride of calcium, to render them uninflammable, are supplied to all these works.

Turret. Class 4 *turret* is only employed on Dover Admiralty Pier. This is a tremendous structure. The foundations are laid 7 fathoms below low-water mark, and the guns are 33 feet above high-water mark. The entire structure is therefore about 95 feet high. The turret consists of a live ring and rollers of steel running on a path of steel laid on a massive cylinder of masonry. On this live ring runs the iron framework (Fig. 4), weighing 240 tons, containing the gun chamber.

Fig. 4.



The armour consists of three 7-inch and two intermediate 2-inch plates, making in all a weight of 460 tons; the guns, carriages and slides make up the total of the running weight to 895 tons. This throws on each of the thirty-two rollers of the live ring a pressure of about 28 tons. The entire diameter of the turret is 37 feet, the interior

32 feet. The interior height of the gun chamber is 8 ft. 8 ins., the height of the turret armour is 9 feet. There is a massive central casting holding on to the masonry, and a thick cylinder of hammered Bessemer steel inside this surrounds the wrought-iron built-up cylinder, which forms the centre of the turret framework. The unabsorbed portion of the blows of impact may be transmitted to this part which is made specially strong. The pieces are 80-ton guns, got in and out through the roof, of which parts are made removable for this purpose. Provision is made for the escape of smoke through the turret top. The gun ports admit of 7° elevation and 2° depression. The glacis round the turret is plated with 5-inch and 3-inch plates. The guns are loaded from under the glacis, the muzzles being depressed for the operation.

Provision for increase.

Throughout the works, above described, the probability of continual increase being called for, has been kept ever in view. This has augmented the difficulties under which the Engineers have laboured. This system of coast defence may naturally be compared with that of Grüson. In doing so it must be borne in mind that breech-loading has enormously facilitated the construction of strong forts, because, as may be seen in Fig. 6, p. 6, Part II., it is only necessary to give the men sufficient height to stand upright some distance back from the wall instead of close to the port as with muzzle-loading. Hence, the forts for muzzle-loaders must of necessity be carried in a cylindrical form higher than those for breech-loaders, which may be curved back into a dome, thus saving wall and giving greater strength to the roof. Moreover, on most systems,[1] much more space is occupied by the working of a muzzle-loader, which must be run back further than a breech-loader. A conical turret with steel-faced armour was tried at Eastbourne, in May, 1886, but is as yet in a very imperfect condition. In justice to Grüson, it must be noticed that casting lends itself to the shaping of a dome with each part proportioned to the work that it is calculated it may have to bear in a way that no system of plates made by rolling or hammering could claim to do. Probably the English forts altogether cost much more than those of Grüson.

In their favour must be urged that they will bear continued fire better,[2] and that it is very easy to increase their strength by adding plates in front of their armour, for which complete provision is made, even to the drilling of holes and insertion of nuts and temporary bolts, to enable the operation to be performed without removing even the front plate. Grüson's cupolas must, it is supposed, be broken up and re-cast in order to increase their strength. With the powers of Artillery ever growing this is a very important consideration. Further, it is obvious that the plate-upon-plate system favours the removal of plates from one part to another readily if wished, an operation that in certain cases might be desirable. *Under the attack of a gun completely beyond the power of the fort,* the wrought-iron would be perforated, and the shell would pass on doing mischief, though in the case of fairly thick steel-faced armour it would be in the form of dead metal, for shells that pass through such armour before exploding are far from realization at present.[1] Chilled-iron, under these circumstances would probably stop every part of the projectile, possibly at the price of its own wholesale destruction, but so long as the wall is fairly whole the men need not fear the next round. Lastly, the vertical walls of our coast forts enable tiers of guns to be mounted one over the other, so as to utilize the area of the foundation to the fullest extent.

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[1] Rendell's system of lowering the muzzle and loading below the glacis may save both in height above the port and in running back.

[2] *See* pp. 7, 12, and 97, Part I.

CHAPTER V.

Brief Summary of Behaviour of Various Kinds of Plates, Backing, &c.

Wrought-iron.

1. *Wrought-iron* yields locally; it is punched or perforated, a clean hole being made in it.[2] The rest of the target hardly suffers appreciably, except close to the point of impact. The entire shield, including bolts, is generally capable of resisting any subsequent blow as stoutly as it resisted the first one. Effect here must be obviously produced by the bare power of perforation of each round taken singly. Partial penetration is practically useless, however often it may be repeated.[3] The shot experiences but little resistance as its point enters, and hence it is well enclosed and supported round its head before the full strain comes on it. Hardness and rigidity of metal in the projectile here tell to the greatest extent, and tenacity to the least. These conditions have favoured the use of Palliser's chilled-iron shot with sharp points. The plate yields at the back opposite to the point of impact by tearing in a cross or star line, letting the point of the shot through the centre.

Steel-faced iron.

2. *Steel-faced wrought-iron,* Cammell's, made on Wilson's patent, or Brown's on Ellis' patent. Here the steel face, which constitutes about one-third of the thickness of the plate, is a harder class of steel than is generally supposed,[4] and resists the point of the shot abruptly, and severely tries the tenacity of its metal. Hitherto, seldom has a projectile held together under these conditions;[5] there is a mechanical force acting something like the outward thrust on the sides of an arch, and the shot sets up, or more commonly breaks to pieces, leaving but little metal lodged in the plate. The plate yields mainly by cracking in radiating lines from the point of impact. In plates badly backed the plate bends slightly back, and very rigid shot occasionally get their points through; but when well backed, the entire plate must be broken

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[1] The excellent Krupp shells, and those of *Firminy* and *Holtzer* fired at Shoeburyness in the summer of 1886 promise well, but a good deal has yet to be done before they carry bursting charges through steel-faced armour, more especially on service, when they would hardly ever strike normally.

[2] *Vide* p. 12, Part I.

[3] *Vide* p. 4, Part I.

[4] Containing perhaps about 0·7 per cent. of carbon.—*Vide* p. 118, Part I.

[5] Firminy and Holtzer forged steel projectiles fired from the 12-inch B.L. gun, passed through 16-inch steel faced plates without fracture in the summer of 1886.

in pieces and displaced before a shot gets past it in any sense. In addition to the radial cracks, concentric ones are apt to be developed, sometimes, perhaps, owing to the tendency of the plate to give back about the point of impact. Obviously, here tenacity in the shot is called for in a much greater degree than with wrought-iron armour.[1]

Solid steel.

3. *Solid steel*, as made by Schneider[2] and used in many foreign ships, though rather less hard than the steel face of compound plates, is as a mass more rigid. It admits the point of the shot at first with less resistance, but it does not yield at the point of impact even when badly backed, and is, therefore, less dependent on backing than compound armour. As the shot enters, it wedges and heaps up the metal round it, the plate coming forward and swelling at the point of impact and yielding by radiating cracks. It may be questioned if a case could be found of a concentric crack being made in steel armour. Nearly all cracks made extend through the metal, but by the employment of a large number of bolts the fragments may be held up, and considerable resisting power maintained after fracture. On the other hand very soft steel plates admit of perforation, and in their character resemble wrought-iron more or less.

Grüson's Chilled Iron.

4. *Chilled-iron* made by Grüson,[3] and used almost universally in foreign coast-armoured defences, is very rigid indeed. The shot seldom gets its point many inches into the metal. The shield transmits the shock through its mass and must be broken up bodily. Chilled-iron is used in large masses, and is best suited to resist single blows, especially in an oblique direction. Under the direct blows of heavy shot of high tenacity, chilled-iron breaks up. Cracks radiating from the point of impact are formed, and the whole shield breaks across. An important requirement in the shot appears to be tenacity, to enable it to deliver its work on the point of impact before it breaks up, which it does, leaving little or no metal lodged in the shield.[4] The best forged steel projectiles shiver to pieces against Grüson's shields. The hardness of the metal and the angle presented by the surface to the line of fire alike tend to produce this result.

Backing.

Backing strengthens the plate to resist perforation better when hard, but saves bolts and fastenings from fracture better when soft. Thus steel-faced iron on granite has resisted perforation wonderfully.

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[1] For compound steel *vide* p. 90, Part II.

[2] *Vide* pp. 118, 133, 147 and 151, Part I. A very remarkable series of experiments was made under Sir Nathaniel Barnaby's direction at Messrs Cammell's, Cyclops Works, Sheffield, in Nov., 1880, on the bending of steel plates of thicknesses of an inch and less, when it was found that steel bending well both at red heat and cold would in no single instance bend without tearing, at blue heat. Cammell's, Brown's, Bolton, Parkhead, Landore, Siemen's, and Steel Company of Scotland steel being experimented on. The author called the attention of manufacturers on different occasions to this, especially with a view to steel boilers. Messrs. Hawthorne's, Newcastle, found evidence of the same tendency in iron. It may be observed that it is not proved that the metal yields under less force at blue heat, but only that it prefers to tear rather than bend when it does yield at that temperature.

[3] *Vide* pp. 1 to 16, Part II.

[4] For chipping the face by concave pointed shot *see* pp. 13 and 16, Part II.

(*vide* p. 61, Part I.). For iron, concrete, brick, &c., (*vide* p. 9, Part I.). Wood layers between plates (*vide* p. 9, Part I.). Air spaces between plates of armour, have the effect of breaking up chilled-iron shot (*vide* pp. 9, Part I., and 50, Part I.).

Bolts. *Bolts* should resist sudden shocks and bear elongation well. The early ships[1] had through bolts with conical heads holding into the armour and screwed ends nutted against the skin (*vide* p. 5, Part I.). French bolts had wood screws with projecting threads holding into the backing (*vide* p. 5, Part I.). Palliser bolt with projecting thread was proposed in 1862, and eventually took the form of the *Palliser-English* bolt with shank decreased to be free from all nipping to prevent local strain and with spherical screw nut fitting into hemispherical bottomed socket to accommodate itself to slight lateral displacement (*vide* p. 6, Part I.). These are used to couple iron plates together in pairs on the plate-upon-plate system. For steel plates Schneider introduced a screw entering a short distance into the back of the plate[2] and leaving the surface and, indeed, the mass of the plate unperforated (*vide* p. 118, Part I.). These bolts are screwed and nutted at the reverse end.[3] In cases where the backing is thin the bolt would suffer, by being too short to give scope for elongation. This evil is counteracted by using an iron pipe-box on the back of the shield through which the bolt is made to pass. This enables it to be prolonged to the necessary length to meet the required stretch, without an unreasonable per-centage of elongation. A hollow iron washer filled up with india-rubber is nutted on to the bolt end. This bears on the end of the pipe-box. Bolts are now generally made of soft steel. They are proved by being stretched by the fall of a heavy weight on a frame held up by a bolt.

CHAPTER VI.

Brief Notes on Manufacture.

The manufacturing processes employed in making armour and projectiles form too large a subject to be attempted here, and in all probability the most important features are just those that the manufacturers would not wish to publish. Nothing therefore is here attempted beyond a brief sketch, indicating the general character of the processes of manufacture of different kinds of armour. They are taken in historical order.

Wrought-iron. *Armour, wrought-iron.*—General Inglis gives the following description, which is quoted verbatim :—[4]

"For this, as made at Sheffield, the best cold-blast pig with a proportion of Cumberland hæmatite is generally used. Roughly speaking, it takes 2½ tons of pig, or 2 tons of ball furnaced iron—that is, of puddle ball—to make 1 ton of finished armour plate, and in the last heating of all, when the iron is in a very costly state, there is a loss by the actual burning away of the iron of about 10 per cent. It takes also about 6½ tons of coal to make a ton of armour.

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[1] The *Warrior*, *Minotaur*, &c.

[2] At Spezia in 1882, Schneider's bolts only entered 2¾ inches into the 19-inch plate (p. 118, Part I.).

[3] For behaviour of shot, *see* manufacture, p. 101, Part II.

[4] Paper read at R. A. Institution, April 29, 1880.

Perhaps the shortest way of giving an account of the manufacture of rolled iron armour will be to say how some one plate in particular has been made, and for this purpose one of the heaviest ever produced is selected.

This was one of the 8-in. plates made for the target to test the 80-ton gun at Shoeburyness. Its finished dimensions were—length 16 ft., width 10 ft., and its weight 23 tons.

For its manufacture 1170 slabs 30 ins. long, 12 ins. wide, and 1-in. thick were made from the puddled ball and bar. These were piled, furnaced, and rolled into 65 plates about 5 ft. square, and from 1-in. to 1½-in. thick, called small moulds. These, again, were piled and rolled into quarter-moulds, and the quarter-moulds into armour-plate moulds, and the pile for the last rolling was made up of three moulds about 10 ft. square, two of 7 ins. and one of 3 ins. thickness. As they entered the furnace for this last heating they weighed about 35 tons; as they came out after about 12 hours they weighed 31½ tons.

They were rolled down in the last rolling from 17 ins. to 8 ins.; so that, in a certain sense, this plate may be said to have been made by rolling a column of iron nearly 100 ft. high down to one only 8 ins. high. The fibrous character of a plate depends largely upon the amount of reduction in the last rolling.

The rolls are plain cast cylinders; those used in the present case are about 3 ft. in diameter, 12 ft. long, and each one of the pair weighs nearly 20 tons. They are driven by very powerful steam machinery, and made to reverse their running, so that the plates are sent through one way and then back again, and so on, the rolls being brought nearer together each time, until the plate is brought down to the required thickness.

The specific gravity of a good iron armour plate is about 7·625.[1]

Armour plate iron is not made for very high tensile strength, but it is essential that it should draw out well, and reduce in cross section some 20 or 30 per cent. before breaking.

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[1] Contradictory statements are made on this matter. Dr. Percy (*Iron and Steel*, p. 868) gives the specific gravity of wrought-iron before rolling as 7·877, and after rolling as 7·86. Sheffield manufacturers have told the author that the specific gravity is increased by rolling, not decreased. It will be seen however that the specific gravity given by General Inglis, 7·625, is considerably less than that by Dr. Percy, in fact, it agrees with what he gives for thin sheet, namely, 7·6. This suggests that the plates are very well rolled, and that Dr. Percy is correct. On the other hand, Sir F. Abel, in a paper read at the Iron and Steel Institute, in October, 1886, on erosion, considered that steel of 7·859 specific gravity had been worked more than one of 7·847. If however the specific gravity is decreased it must be presumed to be due to the fact that the crystals being elongated enormously, the intervals between them occupy a larger proportion of the area of any cross section. There seems nothing unreasonable in this, though doubtless Sir J. Whitworth would have considered that it supported his view that wrought-iron consists of faggots of iron glued together with cinder. This fibrous structure ought however to offer advantages. Dr. Percy states that it is twice as easy to break it along the fibre as across it. As the fibre would run with the length of the plate it would give the plates the maximum strength in the narrowest direction and make it very difficult to break them across.

It has been our practice to prove a very large proportion of the plates made for iron fortifications by shot capable of nearly perforating them. Pieces of those which could not be thus proved have been broken under hydraulic presses, and otherwise treated.

Armour bolt-iron is similar to armour plate-iron (but soft steel is now much used). We require reduction of area of fracture of at least 40 per cent. when broken by falling weight test, and we generally get a larger reduction than this.

Laminated armour.

In the early days of armour, *laminated armour* was used in America to meet the requirements of the moment. This consisted of thin sheets of iron bolted together. These sheets, sliding on each other, facilitated the work of punching, especially by pointed projectiles, because the corners of the torn metal bent back much more easily than is the case with solid plate, and accommodate themselves to the bend. The measure in which plate-upon-plate armour is inferior to equally sound solid plate must be explained on the same principle, a slight inferiority which is thought to be amply compensated by the advantages of breaking joint, and larger surfaces with fewer joints, &c.

Steel-faced iron

A compound or steel-faced plate consists of a wrought-iron "foundation plate" with a steel "face plate" of about half its thickness attached to the front, thus giving the combination of hard surface[1] and tough back or body. There are two processes on which this class of armour is made namely:—Wilson's, carried on by Messrs. Cammell at the Cyclops Works, and Ellis', by the firm of Sir John Brown and Co., at the Atlas Works, both at Sheffield.

Wilson's System.

Wilson's system was first brought into practice, and has been taken up by several firms on the continent. The foundation plate consists of thinner plates each made up separately and finally united, but not thoroughly worked up and amalgamated. It is thought better to keep up the laminated structure sufficiently to cause these layers to break and yield separately, and not in one continuous line. It will generally be found that when a shot destroys a plate of this kind, the layers tear open in steps, any breach made becoming larger and larger as it reaches the back of the plate. It is held that increased resistance is offered by a fracture of this kind, and much more support afforded by the backing.

When the foundation plate has been completed it is at once cleaned of scale, passed into a mould and secured at its edges. The mould is then rotated so as to be up-ended, and steel is poured in to form the face plate. After this, the plate is rolled and finished.

Ellis' System

On Ellis' system, the foundation plate is more completely worked, and when ready for the steel face, it is laid horizontally, and the thin steel plate which is to form the front of the shield is laid on it, being held up at the proper distance to allow of the molten steel entering between the two, by resting on a number of steel pins standing on end. The two plates in this state are passed into a furnace, and when heated are brought out, placed in a mould, and steel is run in between them after they are brought to the vertical position, as in the Wilson process. The steel pins are so far welded to the plates in the furnace that there is no fear of the two plates altering their relative position, or the pins becoming dislodged, and it is probable that they are melted by the molten steel when it is run in. The plate is then finished by rolling to final dimensions. When a plate is required to be tapered towards one edge it is necessary to narrow the space for the molten steel at this part, and to make the iron proportionately thick, for working purposes. Finally, the extra iron is cut away from the back. Fig. 5, herewith,[1] shows the running in of the steel on a foundation plate at Brown's works. A view of the same process at Cammell's would resemble it.

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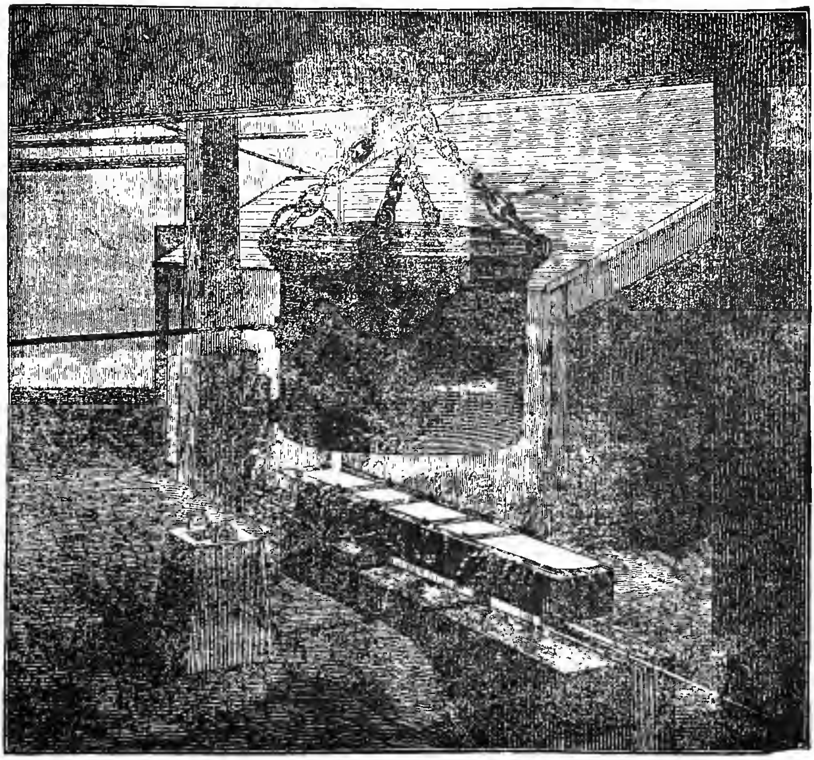
[1] At Spezia in 1882, Brown's steel-face had 0·7 per cent. carbon and Cammell's 0·65, *vide* pp. 117 and 118, Part I.

Fig. 5.



For Wilson's process is claimed special soundness in the body of steel, and power to remove the scale, which interferes with the union of the steel and iron, and also that one re-heating is saved. For Ellis' it is claimed that the face is specially good. This is illustrated by the sharp angles at which the plates may be bent without cracking, angles at which wrought-iron is liable to give way. Under fire, Wilson's plates are softer than Ellis'. Thus penetration is deeper and cracking less in the former than in the latter. Great stress is laid on want of homogeneity by both makers. This should be understood, because this quality, which is aimed at and claimed as a virtue, is pointed out as an evil inseparable from the system by some writers, especially by Lieut. Jacques, U. S. Navy, in an able pamphlet termed "Modern Armor for National Defence." It is believed that while it is desirable to unite the surfaces of the steel and iron as perfectly as possible, the different nature of the substance of the iron causes cracks to stop abruptly, which would otherwise have run through the mass. Figs. 1 and 2, p. 91, are remarkable illustrations of this action. They represent Wilson's steel-faced plates tested at Amager, on Aug. 6th and Sept. 10th, 1885, 5 ft. square by 11·5 inches thick. The steel was $4\frac{1}{8}$ inches, and the iron $7\frac{3}{8}$ inches thick. The plates were actually cut in two to furnish sections after the trial. Fig. 1 shows the effect of a 10-inch chilled-iron Ankarsrum projectile, weight 181·5 kg. (400 lbs.), with a striking velocity of 423·6 m. (1390 feet) an energy of 1660 metre-tons (5358 foot-tons), a perforation of 13·4 ins. of iron, an energy per ton of plate of about 1040 foot-tons, supposing the plate to weigh 5·15 tons. A few face cracks were formed, and the behaviour of plate in stopping the shot is most satisfactory.

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[1] **Taken from Major Mackinlay's paper to the R.A. Institution, p. 604, Vol. XII.**

Fig. 2 is a more important example, because a forged steel projectile was fired weighing 182·5 kg. (402 lbs.) with a striking velocity of 438 m. (1437 ft.) an energy of 1784 metre-tons (5760 foot-tons) a perforation of 13·9 ins. of iron, and energy per ton of plate of 1118 foot-tons. The steel shot would deliver a much larger proportion of its energy on the plate before breaking up. A plate seldom survives a *single blow* of 1000 foot-tons per ton of plate. The behaviour of this plate, which is only slightly cracked at the back, is admirable.

It naturally suggests itself that compound plates might be made with very hard steel faces, and backs of soft steel instead of iron, seeing that soft steel has both greater elongation and also greater tenacity than iron. Experiments of this kind have been made at Sheffield but without success.

Compound steel.

Sir J. Brown and Co. once tried a steel front and back with an intermediate layer of wrought-iron. The steel, however, was not soft at the back, and no great stress should be laid on this trial, which was merely one to test the effect of a break in homogeneity, on a steel plate. Two more important experiments, however, were made as follows:—Messrs. Cammell made a plate, on the compound principle, wholly of steel—that is to say, with hard steel in front and soft steel behind. The steel face had a breaking strain of about 47 tons per square inch, and an elongation of about 1·5 per cent.; whereas the back had about 23·0 tons tenacity, and 25 per cent. elongation. This plate was fired at on board the *Nettle*, at Portsmouth, on March 14th, 1884, under an experimental title. Its dimensions were 8 ft. by 6 ft. by $10\frac{1}{2}$ ins. thick. It was attacked by a 10-inch muzzle-loading gun,

Fig. 1.

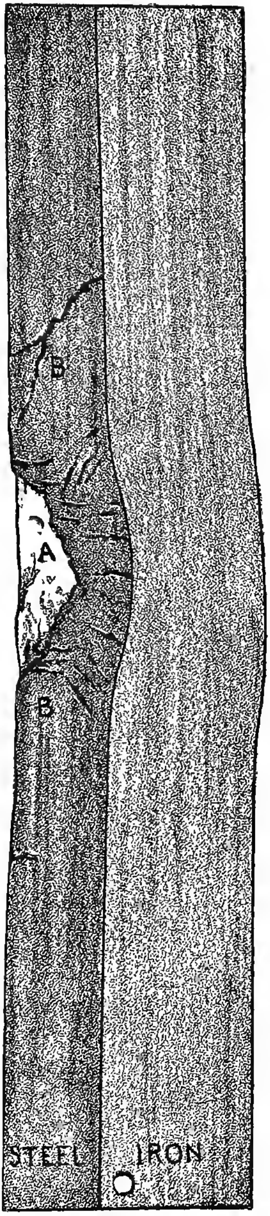
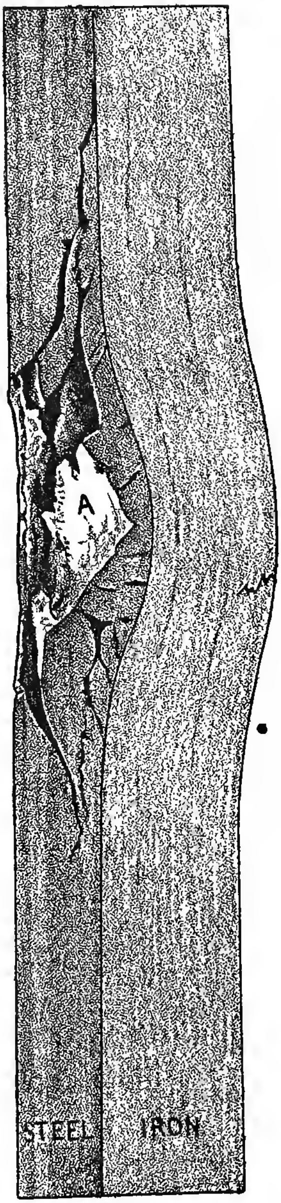


Fig. 2.



with a chilled-iron projectile weighing 400 lb., and a striking velocity of 1364 ft. This would give a total striking energy of 5160 foot-tons, or about 573 foot-tons per ton of plate, supposing the plate to weigh about 9 tons. The calculated perforation would be about 13 ins. of iron, or 9·8 ins. of compound armour or steel. Three blows were delivered on it. The plate stopped the shot well, the projectiles only entering to a depth of about 5 ins. Nevertheless, it did not behave in a way that would meet with approval with English authorities, seeing that it cracked all over in through cracks—*vide* Figs. 1, herewith, and 2, p. 93. It remained held up by its bolts, but was divided into pieces, and was not considered sufficiently satisfactory to encourage further trials in the same direction at the time.

It may be here said that, on the first success of steel at Spezia, it was proposed to try it in this country; but our combatant naval

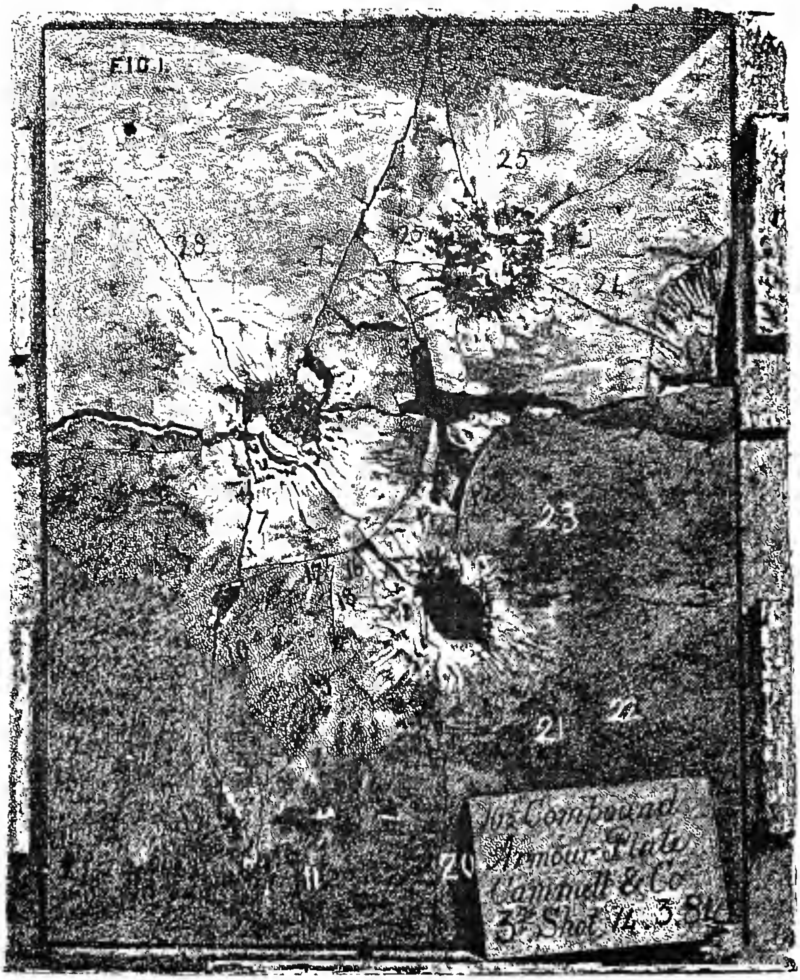
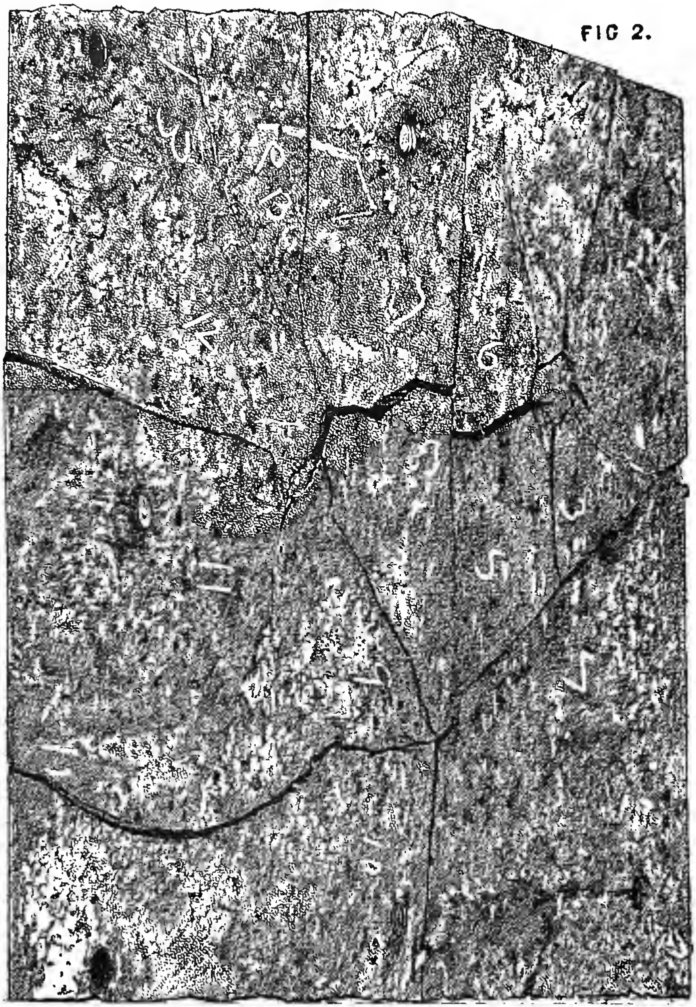


FIG. 1.

advisers positively objected to it, on the ground that it stripped off, and would leave a ship's side bare. It is easy to employ a great number of bolts in a target, but on a ship's side the multiplication of bolts involves expense and weight in the supporting structure. Thus steel-faced armour was only approved on its fulfilling certain rigid conditions—namely, that no through cracks shall be made by the first round fired; it being also stipulated that no one of three projectiles shall get through the plate.

FIG 2.



The experiment with compound steel is especially to be noticed, because it had embodied in it the elements above suggested—namely, a hard face, and a back consisting of steel of greater elongation and higher tenacity than the wrought-iron usually employed, whose tenacity is generally about 17 tons, and its elongation 18 per cent. A single trial is doubtless hardly likely to meet with a large measure of success. Still, Messrs. Cammell are old steel makers, and their first attempt, based on manufacturing investigations, ought to be very good for a first trial. The exact measure of success, however, is not the matter of real significance, but rather the fact that will appear further on—that the behaviour of this steel plate very closely resembled that of Messrs. Schneider's steel plates at Gâvre, and would probably have passed and been accepted by the French Government. So long as such a plate meets with disapproval from our own authorities, there is very little to encourage the further trial of steel. But of this, more presently.

The second significant experiment above-mentioned, was the trial of a compound plate by Sir John Brown and Co., with a wrought-iron back differing from the usual sample, in the fact that the tenacity and elongation of the iron used were both considerably greater. Consequently it might be expected that the plate would have been both stronger and tougher than usual. It happened, however, that it cracked instead of bulging. This result, taken in conjunction with that obtained with Cammell's steel, seems to show that *low* tenacity is a necessity for the metal in the back of a plate, if it is to be kept from cracking through. Probably the action of the blow is too rapid to admit of the plate bending and stretching, unless the tenacity is low. The great power of elongation is consequently useless under impact, unless the plate elongates with but little resistance.

Solid steel.

Steel armour has been made experimentally in this country by Sir J. Whitworth (*vide* p. 68, Part I.), and also in thin plates supplied for service, as in the turtle back scales which cover the *Polyphemus* (*vide* Fig. 12, p. 114). The best heavy steel armour, however, has been made abroad at Messrs. Schneider's works at Creusôt. The steel is not generally so hard as that employed in the face plates of compound armour.[1] It is hammered down from a great thickness under a 100-ton hammer. It is annealed and the face tempered in oil, so it is said—but it is difficult to get authentic information—and finally annealed again. It is difficult to do justice to steel armour in England. Messrs. Schneider not unnaturally decline to supply plates for competition in this country unless a large order is guaranteed to them. It is desirable however to say something on the subject. It appears that solid steel plates can be made soft, to behave more or less like wrought-iron, or they can be made hard, in which case they resist penetration well, but break through. Hence it will be found that Schneider insists on a great number of bolts, which hold up the fragments and enable the plate to offer great resistance after it is broken through.

Schneider's steel armour.

Gâvre trials.

Photographs may be seen of plates fired at at Gâvre for the French Government, which were passed as samples of lots to be accepted, which would probably have been rejected by our own authorities. They are plates of 18 inches thick and over. Unfortunately we have tried our

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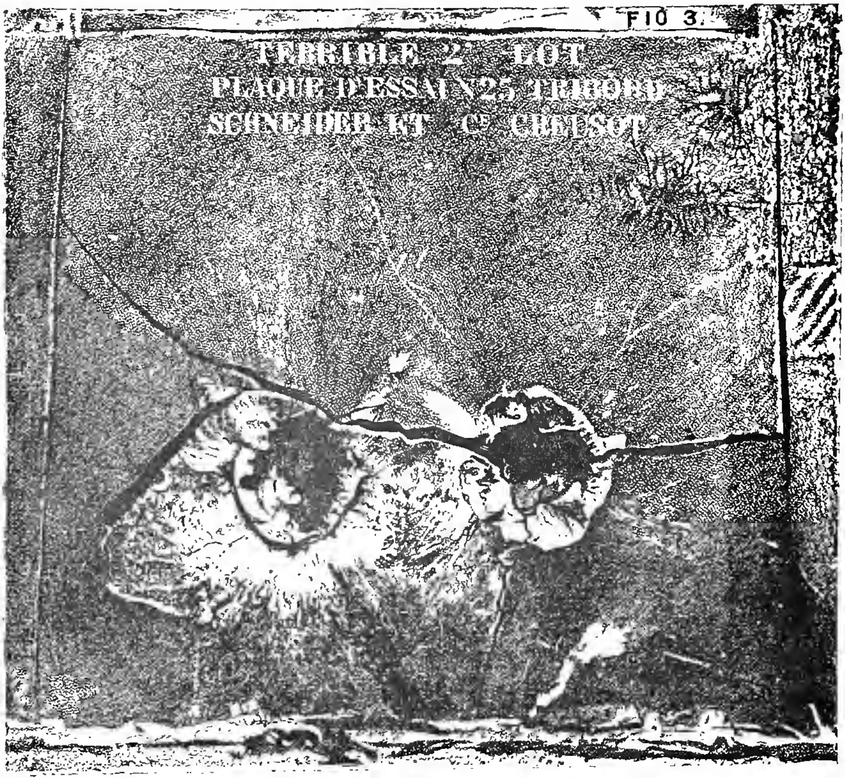
[1] At Spezia, in 1882, Schneider's plate was said to contain about 0·45 per cent. of carbon. It was hammered down from a thickness of 7 feet to one of 19 inches (*vide* p. 118, Part I.).

18-inch plates but seldom in this country. There has no gun larger than a 10-inch muzzle-loader been fired on board the *Nettle* we believe; and, strange as it may appear, our supply of 18 in. plates can hardly be said to have been proved at Shoeburyness or anywhere else. 18-in. experimental plates have been attacked at Shoeburyness, but this is not the same thing as the sample plates being tested and passed in the usual way for each lot supplied to our ships. The omission of a test, however, is one thing; the approval of plates of proved inferior power is another. Figs. 3, herewith, and 4, p. 96, show the front after the 2nd and 3rd blows, and Fig. 5, shows the back of a solid steel Schneider plate, the sample of the second lot of plates which were tested for the French Government at Gâvre and delivered for the *Terrible* during 1881 and 1882. This sample is selected because a view of the back as well as of the front is taken. The thickness of the plate was presumably 19·5 ins., the plate being for the belt of the ship. It was attacked by a 32^{cm} (12·6-in.) gun; the weight of the projectile was therefore probably 761 lb. The striking velocities of the three rounds 1430·8 ft., 1430·8 ft., and 1504 ft.[1] The projectile was a chilled shot, as may be seen in the engraving, from the white radiating splashes of metal. The gun is not a match for the plate. The perforation would

FIG 3.



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[1] E = 11930 foot-tons.

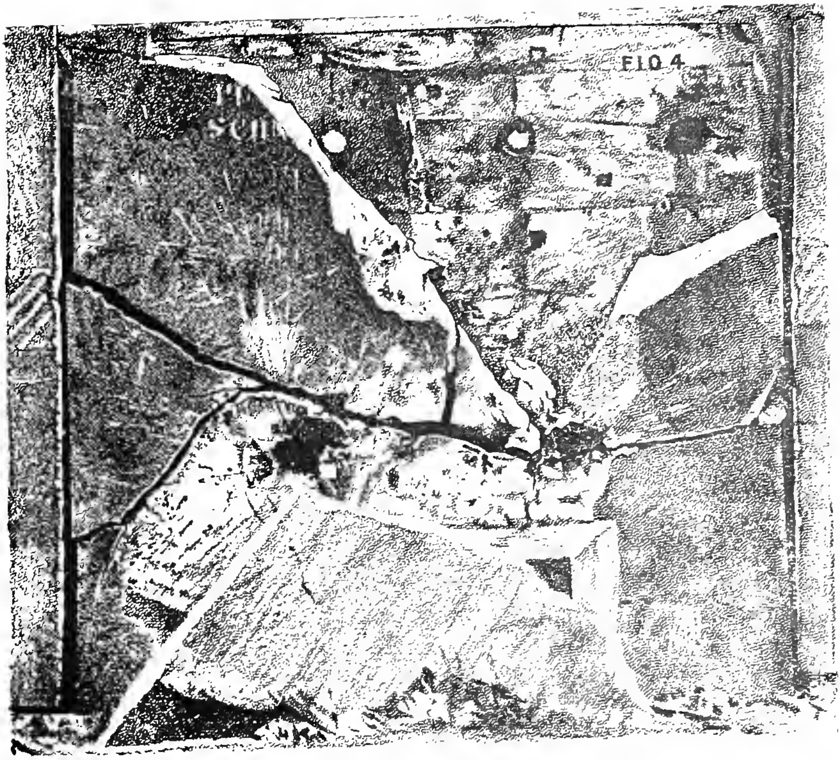
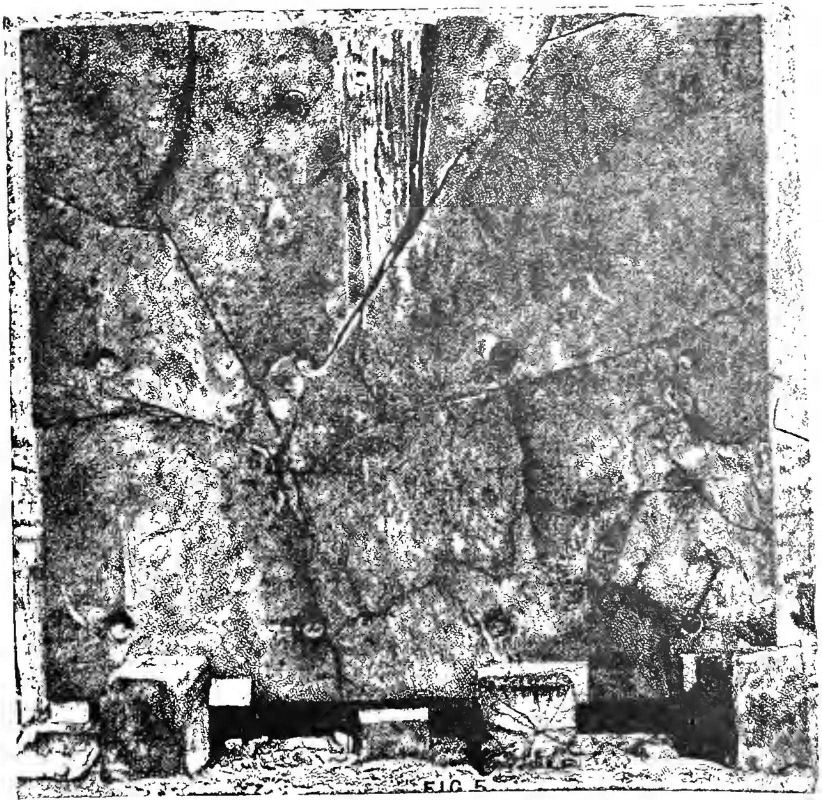


Fig. 5.



be only equal to 17·8 ins. of iron, or about a 13·36-in. compound or steel plate. Suppose that the plate only weighed about 21 tons, the shock would not be greater than that on the Wilson compound steel experimental plate above-mentioned. The plate, however, probably weighed 27 tons, and if so, the shock per ton was but small. Every plate tried for the *Terrible* appears to have cracked through on the first blow, and thus would have been rejected if tried at Portsmouth. An 18-in. compound plate at Shoeburyness received a blow nearly corresponding to this on July 21st, 1880, (*vide* p. 100, Part I.) with insignificant effect from the 12·5-in. gun, with a chilled-iron projectile striking with a velocity of 1504 ft., the weight being 828 lb., and an energy per ton of 541 foot-tons.

Both Brown and Cammell's plates, when below 12 ins. thick, have borne an amount of work out of all comparison with this.[1] An 11-in. plate of Brown's, 10 ft. by 5½ ft. in area, at Shoeburyness received three blows from 9-in. chilled shot, one blow from a 9-inch steel projectile, and two blows from 12·5-in. (38-ton gun) steel projectiles weighing 840 lb. and 845 lb. with 1425 ft. and 1413 ft. velocity and 19·8 in. perforation, and about 11,820 foot-tons and 11,690 foot-tons. In all 38,471 foot-tons, or, taking the plate at 11 tons weight, 3497·4 foot-tons per ton of plate. Discs of metal were nearly or quite separated by the two last blows; but the backing was sufficient to stop them, and the plate held fairly together except one corner. This, of course, was a result beyond all comparison with what we have given above, for here an 11-in. compound plate held together and stopped blows which were probably as severe as those which broke up the French steel 19·5-in. *Terrible* plate, the respective energies are 11,820 and 11,930 foot-tons, but the English plate was attacked by cast steel and the French one only by chilled-iron projectiles, so that the former probably delivered the more energy into the plate before breaking up. It is fair to remember, however, that only a limited number of results from Gâvre come to us, and that these are doubtless worse than would now be obtained; although, as we have nearly the whole of the samples tested for the *Terrible*, they represent fairly the quality of the supply at that time. It is quite possible that some very excellent samples might now be produced from Gâvre, although hardly likely to be better than one which is to be noticed presently. The Schneider plate tested at Spezia in 1882 is enormously better than the *Terrible* samples. This plate had no visible crack on the first round, and it received in four blows 3882·2 foot-tons per ton of plate. It was, however, by that time broken up, the upper portion of the plate hanging loosely out of its place, and large fragments detached altogether (*vide* Fig. 19, p. 126, Part I.).

The 1884 Schneider plate allowed the shot to pass clean through it, so that, excellent as the plate appeared, it is impossible to argue definitely on it. To do Schneider full justice, then, take the case specially selected and put forward by Lieutenant Jacques, as the crowning success in the shape of steel plates fired at at Gâvre, viz., that tested for the *Admiral Baudin*, on March 7th, 1884. (Fig. 6). Here three rounds were fired at a plate 12 ft. 9 ins. long, 8 ft. 2 ins. wide, and from 18 ins. to 20 ins. thick, weighing 35·45 tons. The 32^{cm} (12·6-in.) gun attacked it with three chilled-iron projectiles, the two first striking it with velocities of 1518, 1518 ft., and on places 18·5 ins. thick, and the third one with 1593 ft., on a place 19·8 ins. thick. The last gives a perforation of 19·44 ins. of iron, or 14·58 ins. of compound on steel.[1] The plate looks well in the drawing, but the test is not a severe one; chilled projectiles were employed, the heaviest blow being only about 378 foot-tons per ton of plate, and the whole three only making up 1064 foot-tons per ton of plate. The shield, moreover, is apparently broken entirely through into two pieces, and only preserves its fine appearance from being well bolted up; and this may lead on to the great distinguishing characteristic of solid steel as compared with compound armour when both behave fairly well. This, which has been before stated, appears to be as follows:—Steel armour stands up rigidly, breaking up in through cracks, but if well bolted remains in its place.

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[1] *Vide* p. 108, Part I.

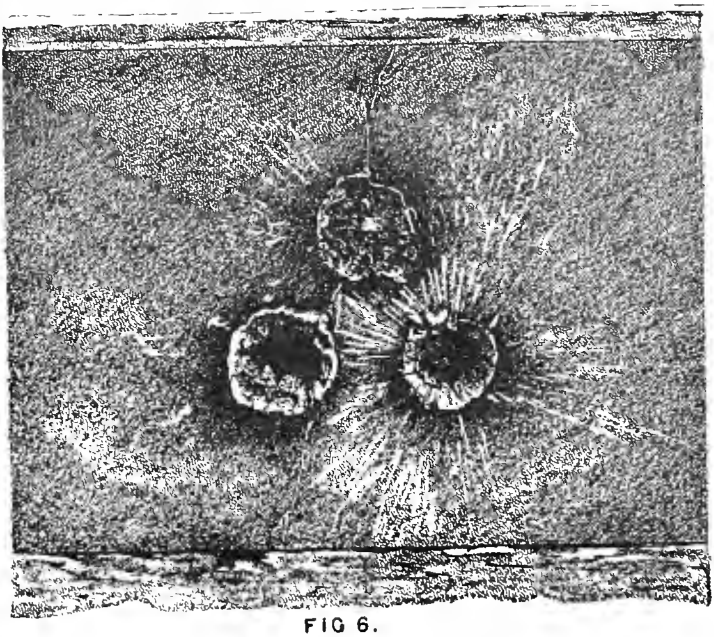

FIG 6.

Effect of bolts.

How successfully bolts may be employed may be seen by an inspection of the back of the steel plate given in Fig. 5, p. 96, in which it may be observed that the cracks seldom run through the bolts. With this experience it is no wonder that Schneider insisted on having twenty bolts in the 1882 trial, when Cammell and Brown competed with only six bolts each. Schneider was undoubtedly right, Cammell and Brown should have had the same; but their encouraging experience with smaller plates and the limited firing trial of 18-in. plates rendered them more liable to be caught in this way than Schneider. Now to consider another point—namely, the element of certainty in behaviour. The variation in the quality of steel is probably always greater than in iron; but there is another shape in which the caprice of steel is shown—namely, in spontaneous fracture.

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[1] E = 13390 foot-tons.

The extraordinary statement is made on authority which ought to be good, that out of the steel plates supplied for the *Terrible*—about ninety in number—eighteen actually cracked spontaneously. Of these, fourteen broke at Creusôt, either after tempering or after annealing; one cracked at the time of dispatch to the port, and three broke while in the port of Brest; but before they were placed on the vessel. If this is true, the *Terrible* is clad in very capricious armour, armour which would break and crack wholesale under fire, and possibly would develop cracks in severe changes of temperature. If, however, it is bolted on the ship as well as Messrs. Schneider generally bolt it, it would protect the ship well under heavy blows in spite of its cracking. On the other hand, the continued fire of comparatively light guns ought to produce an effect on it disproportionate to their power. It must be admitted, that a steel 18·9-in. plate used for proof of 5·9-in. projectiles at Spezia recently received a great many blows without a great loss in resisting power. It cracked through in broad lines, but if well bolted it would resist any fire of 6-in. guns likely to fall on it. Still, 5·9-in. guns are very insignificant pieces to attack an 18·9-in. plate. After considering all the facts above discussed, what are we to conclude as to the relative positions of steel and steel-faced armour?

Solid steel and compound plates compared.

In spite of a natural preference for English manufacture, it will be seen that in the earlier pages devoted to this subject, written before the above information had been obtained, it had been contemplated that steel-faced armour would be displaced by steel—steel on the compound principle perhaps, but steel in some form, sooner or later. Not so much on account of actual results, as because of the great possibilities of steel generally. Just as steel had displaced iron in boiler plates, guns, and projectiles, so it seemed likely to do in armour.

Confidence was not expressed in steel armour, however, in an unqualified way, because, although there had been disappointment in some larger compound plates, and better steel plates had been made on a larger scale, compound plates of 12-in. or below had repeatedly beat steel in competitions. Now facts have been brought to light that raise the question whether steel-faced iron plates may not finally prove the best, and certainly forbid admitting that steel has shown itself superior up to the present time.

The facts referred to are:—(1) The cracking of our own steel experimental plates, made with soft steel backing, and still more the cracking of iron backing when it possessed the very qualities supposed desirable—that is, high tenacity coupled with great elongation. (2.) The records of the *Terrible* plates, and the conviction that, even in the selected specimen of the *Baudin* sample, the plate is broken entirely asunder by comparatively light blows, and those with chilled-iron shot, which have long since, even in England, been pronounced inefficient for the attack of steel or steel-faced armour. If it be denied that the plates are cracked through, why is not the back exhibited? And if the plates will bear really severe tests well, why are guns of such disproportionate power used to prove them, and those with chilled projectiles? (3.) The strange account of the spontaneous cracking of steel plates. (4.) The last victory of the compound plate over the steel at Pola, showing that on the scale on which compound plates have been continually tested and best worked, steel has never been able to compete with them. These facts ought to be met with *actual* facts and figures before we are justified in passing them over.

Happily we are not greatly concerned as a country which kind of armour is eventually adopted. Cammell and Brown have the plant for making steel plates to-morrow, if desired.

At Brown's a gigantic press is in course of erection, capable, it is thought, of turning out sounder steel plates than could be obtained by hammering. There is little prospect, however, of steel displacing steel-faced plates, especially as a Brown experimental steel-faced plate has recently (April, 1887) stopped a Holtzer shell with remarkable success.

It would be right to try steel in this country. The question of superiority is quite an open one yet. The prospects of success for solid steel would, under present circumstances, much depend on the power to give it a harder face than has hitherto been given to it, coupled with a softer back. It must also be shown to be free from the liability to spontaneous fracture or brittleness from atmospheric conditions. There is something pitiful in the thermometer being consulted, and in the circumstance of a steel plate having to be warmed before firing at it, as it is stated took place at Amager in the winter of 1883-84. Should the Admiralty change their minds, and conclude that the fact of plates breaking through does not signify so long as they are held in their place by bolts, the prospects of steel in this country will be much improved; but compound steel ought in the long run to have a better chance than solid steel. So long as we expect to take down our plates intact and look at their backs after impact; and further, if we test them under oblique fire where a hard surface tells most, and if we back them well, probably solid steel is a long way from competing successfully with steel-faced plates.

At some time steel may probably become more trustworthy, it may possibly, eventually, attain the property of elongating instead of cracking under the blows of shot; but this is almost saying what we all know, that steel is daily made more and more like wrought-iron in a pure form. With this a hard face does not seem attainable. At present those who employ armour on their ships must take a practical view of the matter and choose between the properties possessed by the two kinds as they are now presented to us, or are likely to be presented for some time to come. *Compound armour,* with *a steel face and soft iron back,* is likely to hold its own as the safest and most reliable plate for ships under present circumstances, while for facing granite or other hard material it has shown extraordinary powers.

NOTE AND CORRECTION, ON P. 100.

The projectile mentioned in Line 19, p. 100, Part II, was a Firminy not a Holtzer Shot. A Brown plate stopped a Holtzer experimental Shot in November, 1886, but not one of the lot mentioned, p. 103, as might have been inferred from the above statement.

On April 1st, 1887, a 6-in. Hadfield forged steel projectile fired from a worn gun missed the mark, and buried itself in side structure and granite, slightly injuring the point. The same projectile again fired, perforated a 9-in. compound plate and 2-ft. of oak, and penetrated 32 inches into granite, when it eventually broke, but was not set up.

The ballistic powers taken from the results hitherto obtained with the projectiles of the heaviest representative English and German BL Guns, are as follows:—

	Weight of Gun. Tons.	WEIGHT OF		Diameter of Shot. in.	$\frac{W}{D^3}$	V ft. sec.	E ft. tons.
		Shot, lbs.	Charge lbs.				
Krupp	119	2028·25	846·6	15·75	0·519	2000	50780
Elswick	110½	1800	850	16·25	0·420	2148	57580
Royal Gun Factory ...	67	1250	630	13·5	0·510	2025	35560

The powers of the Krupp and Elswick Guns are thus brought more nearly equal than shown on Tables XV. and XVIII.

Naval powers employing steel-faced and steel armour.

The following is a list of the naval Powers employing steel and compound armour at the present time:—England, compound; Argentine Republic, compound; America, compound, but most likely steel will be tried; Austria, compound; Brazil, compound; China, compound; Denmark, compound; France, compound and steel; Germany, compound; Holland, compound; Italy, *Italia* only compound, the other vessels steel; Russia, compound; Spain, steel recently ordered for one ship, compound talked of for another; Sweden, compound and steel.

The makers are for *steel:* Schneider, at Creusôt. For *compound* (on Ellis' patent) Brown, at Sheffield: (and on Wilson's patent), Cammell, at Sheffield; Marrel, at Rive de Gier, Loire; La Compagnie Anonyme des Forges, at Paris; La Compagnie des Hauts Fourneaux, St. Chamond; the Dillingen Works, in Germany; and Tjora Iron-works, Kolpino, St. Petersburg.

Projectiles.

Projectiles for the attack of armour have been made of ordinary cast-iron, wrought-iron, chilled cast-iron, and steel, and compound shot of chilled cast-iron in conjuuction with steel have been used experimentally.

Ordinary cast-iron.

Ordinary cast-iron soon proved ineffective for thick armour. It may, however, be employed in common shell against thin armour. Common shell have perforated unbacked iron of a thickness equal to half the diameter of the shell (*vide* pp. 51 and 52, Part I.). One common 9-inch shell from the *Shah* perforated the side of the *Huascar* (4-inch plate) and burst in the backing. Wrought-iron shot hold together but spread out against the plate, it is scarcely likely that they could be used with advantage even for racking purposes (*vide* pp. 13 and 14, Part I.). Steel shells with heads screwed on were proposed by Major-General Alderson in 1865 and acted fairly well. Chilled cast-iron were brought forward by the late Sir W. Palliser in 1863[1] and have been made in the Royal Arsenal and other factories almost without interruption since. They are made from special mixtures of iron, Ridsdale, Cwmbran, pig and broken projectiles have been principally used, doctored at times with "*ilmenite.*" The projectiles are cast point down in moulds of iron for the heads and sand for the bodies. By means of the conducting power of the metal the point and head become sufficiently chilled to cause the iron to be white, while in the body the carbon separates to a certain extent.[2] Chilled metal is specially hard and dense and has great crushing strength, but it is brittle, the body is intended to have more tenacity. The hardness and crushing strength of chilled metal remain almost unrivalled to the present time. The points never flatten, and the metal remains remarkably cool after impact. The best

Palliser chilled iron projectiles.

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[1] *Vide* p. 4, Part I. Lieut.-Colonel Barlow, R.A., contributed a paper on "The manufacture of chilled and other Projectiles in the Royal Laboratory," in R.A.I. Proceedings, Vol. IX., No. 3, 1875, to which reference may be made for details.

[2] When in the Royal Laboratory, about 1866, the author, in a very limited imperfect way, compared the conditions of the same metal when chilled and cast in sand by taking specific gravities and acting on them with nitric acid. The specific gravity appeared to be increased about 3½ per cent. by chilling.

steel has only recently been made to stand as well up to its work, at the point, where compression only is concerned. Chilled projectiles fracture very easily if exposed to oblique blows in store, and are liable to crack from molecular action. In short the metal is in a constrained unnatural condition, but its excellence for punching work, especially in soft armour, has caused it to be tried in points of shot which are made of steel or strengthened by steel.[1] The peculiar weakness of chilled metal was remarkably well illustrated in its pulverization in air space targets.[2] Chilled shot depend on getting their heads into the armour before the full shock comes on them, and are apt to break up badly against the hardest kinds of plates, that is against chilled-iron shields, and against solid steel. Against steel-faced plates chilled-iron in this country has occasionally produced better results than could have been anticipated.[3] Nevertheless, seeing that armour is likely to become increasingly hard and that chilled-iron and solid steel are much used abroad, the supersession of chilled-iron [4] by steel has been obviously inevitable; the manufacture of chilled projectiles was discontinued in the Royal Laboratory in October, 1886, though since resorted to, to meet immediate demands. For sections showing projectiles chilled in different ways *vide* p. 89, Part I. In judging of the harshness of fracture, novices are specially warned against the fracture shown by pieces chipped off near the surface, which often exhibits a beautifully fine silky texture, while a deep normal fracture is much coarser. Steel has been sometimes combined by mixing, by melting up with iron in chilled-shot, both by Krupp [5] and in the Royal Laboratory, as well as in Wilson's shot, where the point is cast of chilled-iron and the body of steel.

Supersession of chilled-iron by steel.

Steel projectiles.

Steel projectiles have been made of innumerable kinds both forged and cast. Alderson's, mentioned above, were some of the first tried. As it is impossible at present to specify any distinct steel shot or shell as service projectiles, it is better to say very little generally and refer to each steel projectile under the head of particular experiments. Whitworth's forged steel projectiles at first performed the most remarkable feats in England and Italy. They invariably have a small hollow up the axis and a point screwed into the head. They can be fired through great thicknesses of wrought-iron repeatedly, almost without deterioration, even when the heads are undesirably blunt. They cannot be burst by powder. Cammell's have produced good cast-steel projectiles which have held together under impact at very high velocities; a Hadfield cast-steel projectile passed through a steel-faced plate in 1884 without breaking up;[6] but more experience is needed to develop cast-steel shot in this country, especially for the larger natures of guns. Krupp's steel projectiles have stood up and behaved generally in the same manner as Whitworth's some years ago, and great progress has been made in the development of steel projectiles on the Continent, while England has stood still. In a competitive trial of 6-inch steel projectiles at Spezia in 1886, an 18 or 19-inch steel plate was attacked by direct fire. The whole of Krupp's projectiles entered to a depth approaching nine inches and rebounded without serious deformation. Holtzer claimed that the best result was obtained by one of his projectiles. The Italian officers considered Krupp had succeeded best, probably because Holtzer's shells, which varied in quality and measure of success, were considered to be in an experimental stage, while Krupp had achieved a fixed standard of excellence. In the summer of 1886, Firminy and Holtzer's 12-inch steel shells passed without fracture through 16-inch compound plates at Shoeburyness. The Firminy shell struck a weak place in a plate behind the target and remained unbroken. The Holtzer shell struck a sound place and then broke. The best forged steel projectiles appear to be made of steel, sufficiently soft to allow of finishing with a cutting tool in a lathe. They have slight projecting bands, at base and shoulder, to facilitate bringing the shot to exact dimensions at the larger part. The front part of the projectile is then hardened and tempered, and the bands of the shot ground to exact dimension. An excellent lot of Holtzer projectiles were passed into the Service in March, 1887.

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[1] As in Wilson's and Palliser's experimental projectiles.

[2] *Vide* pp. 9 and 50, Part I.

[3] *Vide* p. 157, Part I. Many unpublished experiments also bear this out.

[4] For comparative effects of chilled and steel projectiles against chilled-iron shields, *vide* pp. 6 and 12, Part II.

[5] Fragments of such projectiles at Meppen in 1879, puzzled some visitors including the author.

[6] *Vide* p. 149, Part I. The plate was an injured one.

French steel shells generally contain from 1 to 2 per cent of chromium. Fragments of point and base of Krupp's shell fired against Grüson's shield at Spezia in 1886, brought to England and tested, contained respectively 0·891 and 0·864 per cent. of carbon but no chromium.

CHAPTER VII.

ARMOURED STRUCTURES.—SHIPS.

It would be unwise to attempt to deal with this subject, further than to give a few facts and such general rules as may be useful to those who only are interested in the question, so far as it concerns the action of guns and armour. An armour-clad ship is a sufficiently important machine, and the number existing in the world is sufficiently limited for each ship to have an individual character and reputation, which is known and recorded in all centres of information on naval matters.[1] At the Admiralty, for example, there exists a quantity of information, obtained in many cases confidentially, but which it is to be presumed would be utilized in time of war. It can hardly be doubted that in case of war breaking out with any nation, a description of each of the enemy's ships, with a cut showing all her characteristic features, would be issued to our vessels and coast batteries. Even under these circumstances, a few notes as to the classification of ships might be useful to those who have to engage with ships without having made them their study. For practical purposes, dealing only with their armour, armour-clad ships may be divided into the following classes:—(1), *Broadside, old-fashioned, with guns distributed.* (2), *Masted sea-going modern types, including barbette, central battery, and turreted masted vessels, as well as protected ships.*[1] (3), *Mastless turret.* It will be found that vessels will not range themselves exactly under these classes, wide as they are.

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[1] For descriptions of ships *vide* Brassey's "Naval Annual," "King's War Ships and Navies of the World," and "Kriegsschiffbauten Kronenfels." The author is much indebted to Sir Nathaniel Barnaby, the late Director of Naval Construction, for answering all questions raised by him very fully.

Old-fashioned broadside ships.

Class (1). *Broadside, old-fashioned ships, with guns distributed.* In this class the armour is thin, running from about four and a-half to six inches. It extends however in some cases nearly entirely over the side of the ship. Thus, weak as such ships are, they can in hardly any place be attacked by shrapnel fire or that of machine guns, or even quick-firing 6-pounder guns. Their own guns are distributed along the greater part of the side of each ship. The *Minotaur*, or the *Provence* or (French) *Heroine*, fully represent this class. It is probable that common shell from 12-inch guns might be used against them,[2] at the same time it is difficult to speak with confidence, common shell having been only tried against unbacked plates, and against the *Huascar*, when a 9-inch shell got through her 4-inch plates and burst in the backing. Palliser shell filled, acted with terrible effect against the *Huascar* turrets, whose armour was about the same thickness as most of this class (viz., 4½ inches of iron backed by 10 inches of teak). As the armour of this class of ship is wrought-iron it must be perforated, and comes under the rules for that class of attack, that is, the effect depends on work per inch circumference of shot. The fire of guns able only to partially penetrate the sides is useless, however long continued. Such guns are only available for what has been termed the secondary attack (masts, &c.) Ships of this class however might be perforated by almost any modern rifled gun. Even the 7-inch old type Woolwich gun would perforate most of them directly (the *Minotaur* up to over 1200 yards range). Being deficient of deck armour they are specially open to attack by plunging fire or vertical fire, but as their guns cannot train through a large angle these vessels would engage nearly broadside on, a position favourable to the attack of their sides rather than their decks.

Modern masted sea-going ships.

Class (2) *Masted sea-going modern types.* The characteristic of the armoured protection being that it is very thick in important places, while many parts are left without any armour. Generally speaking, the heavy guns are concentrated either in a citadel at the centre of the ship or in barbette towers, or turrets, but in some instances a broadside battery of medium guns exists without any armour. The *Admiral Duperré,* for example, has 14–5½-inch guns (*vide* Fig. 1) without armour. Our own *Shannon, Nelson* (*vide* Fig. 2), and *Northampton* have their 9-inch broadside batteries unprotected. These latter do not profess to take rank as fully armoured vessels, being termed "pro-

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[1] Sir N. Barnaby in his *Naval Review* of 1886 divides ships into—(1) Armoured with armoured gun positions; (2) Protected with unarmoured gun positions; (3) Unprotected.

[2] *Vide* pp. 51, 52 and 54, Part I. The disc struck out by this class of projectile would be impeded by backing to a great extent, and failing experiments it is difficult to speak with any confidence.

Fig. 1.

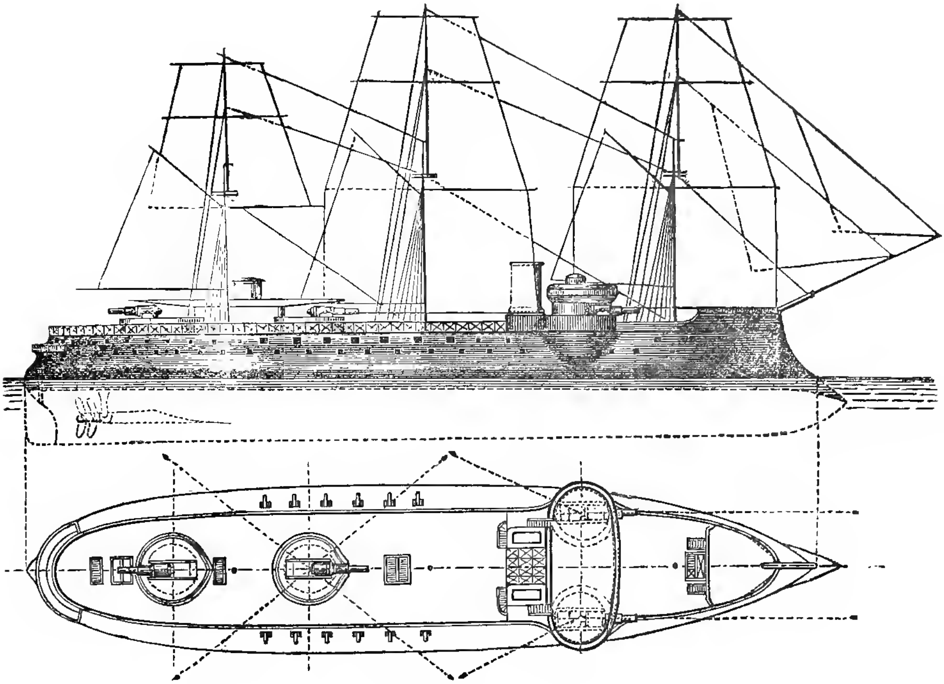
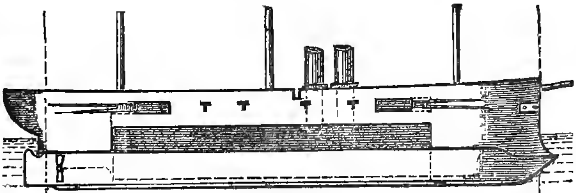
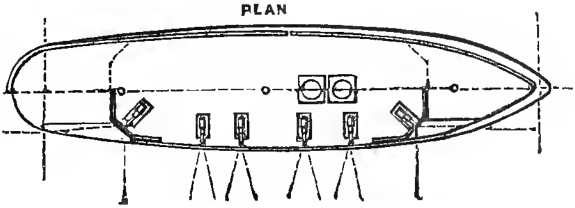


Fig. 2.



ELEVATION

PLAN



tected ships" which are constructed to engage "head on" with their most powerful guns, in which position they are protected by armour both in front of the 10-inch guns and across the bows of the vessel in a bulkhead. It does not seem worth while distinguishing this class, however, seeing that both in the French and Italian navies some of the most powerful ships have guns similiarly exposed. It is only possible, then, to direct attention to a few features that may be found, and to depend on individual descriptions of each ship for further information. Speaking generally, the French vessels have the peculiarity of mounting their guns very high above the water and firing them *en barbette,* not on the disappearing system carried out in our *Temeraire,* but with the men exposed above the *barbette* armour. There is a steel plated structure overhead which protects them from the fire of machine guns in the tops of vessels, but the exposure of the men to mitrailleuse and shrapnel fire is a remarkable feature in the French *barbette* tower ships.

These ships would seldom suffer from the attack of their decks by guns as they could very seldom be struck at a descending angle exceeding 10°, and British ships, and probably many foreign ones, have deck plates to resist at 10° the same fire as the side armour resists direct. At anchor their decks might be assailed in a dangerous manner by mortar fire, and often great injury might be done in the structure above the armoured deck. Their unarmoured parts might be attacked by common and shrapnel shells. Common shell require a quicker acting fuze than the Pettman G.S. to burst violently. Shrapnel being only required to break up, may be fired without any fuze,[1] as impact against the thin iron side of the ship breaks them up. It would seldom be possible to strike a ship below her armour belts even in the roughest weather in which she is likely to fight. A ship's conning tower is an obvious object for attack. There is little to be done by cutting down her funnel.[2]

If the primary attack of the side armour is undertaken, it is important to know if it is iron, steel-faced, or steel. The former suffers only by perforation; and *partial penetration,* even repeated many times, produces little effect in action beyond starting bolts and producing langridge. Steel-faced and steel plates suffer probably in proportion to the total energy of the shot striking them. Even the best steel *filled* shell are seldom useful against thick armour; but this is more fully discussed under the head of Class 3. Fig. 3, p. 107, shows the Chilian vessel the *Almirante Cochrane,* well known from her share in disabling the *Huascar* (*see* p. 119); she is armoured from bows to stern at her water-line, her six heavy guns are in her central battery, terminating at her main-mast. She is a fairly typical ship of her date (1874), designed by Sir E. Reed.

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[1] *Vide* p. 48, Part I.

[2] The *funnel* may appear to be a tempting mark for light guns, but little can be done by striking it above deck, as the following consideration may show:—The boilers are placed low down in the hull, and the funnels must be measured from the fire grates. Suppose the total length of funnel to be 50 ft., and that it is cut down to 30 ft. The diminished power of generating steam will be to the original power in the proportion of $\sqrt{33}$ to $\sqrt{50}$, that is 5·5 to 7·1. The ratio of the speed is, nearly proportional to the cube root of the generating power, that is, as $\sqrt[3]{5{\cdot}5}$ to $\sqrt[3]{7{\cdot}1}$, or about 1·763 to 1·920. In other words, the vessel would only lose 1 knot in 12 by such an injury—though inconvenience might doubtless be felt from the escape of smoke on deck.

Mastless ships.

Class (3) includes all *mastless*[1] *turret* ships and *mastless barbette* ships whether sea-going or coast defenders. Generally they are more heavily clad, both on their sides and deck, and carry heavier guns, but fewer of them than any other class of vessel. The *Italia* and *Lepanto* (*vide* Fig. 4 p. 108, and Fig. 5 p. 109) which have no side plates, and depend entirely

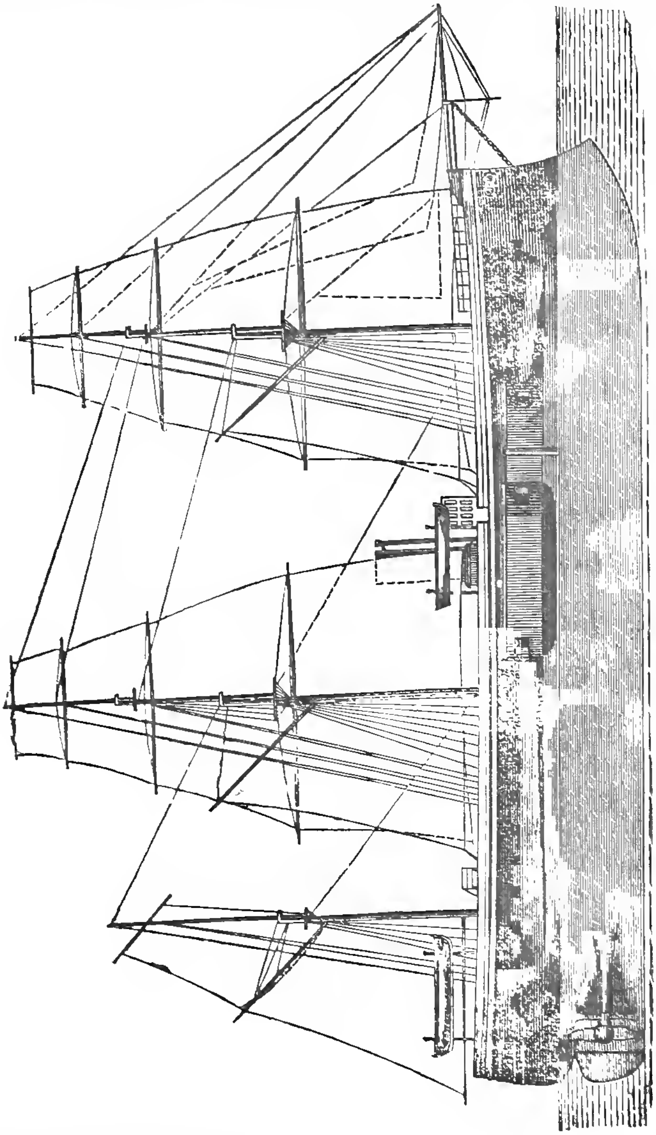

FIG. 3.

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[1] That is carrying only signal masts.

Fig. 4.

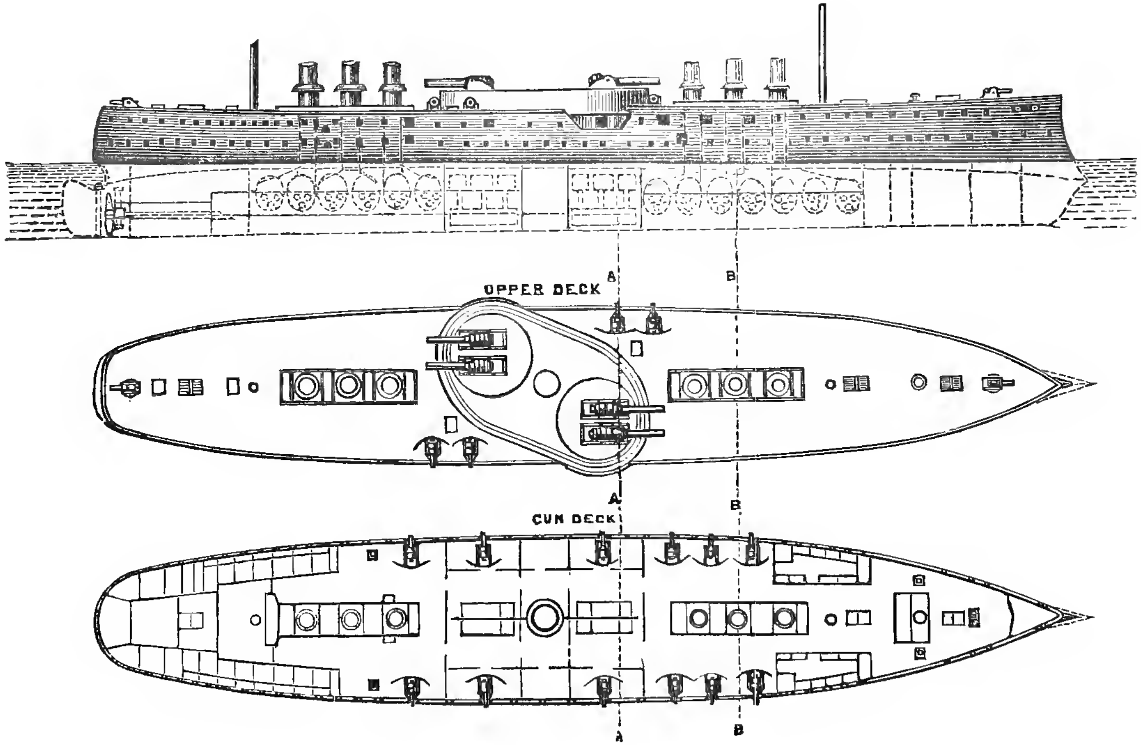
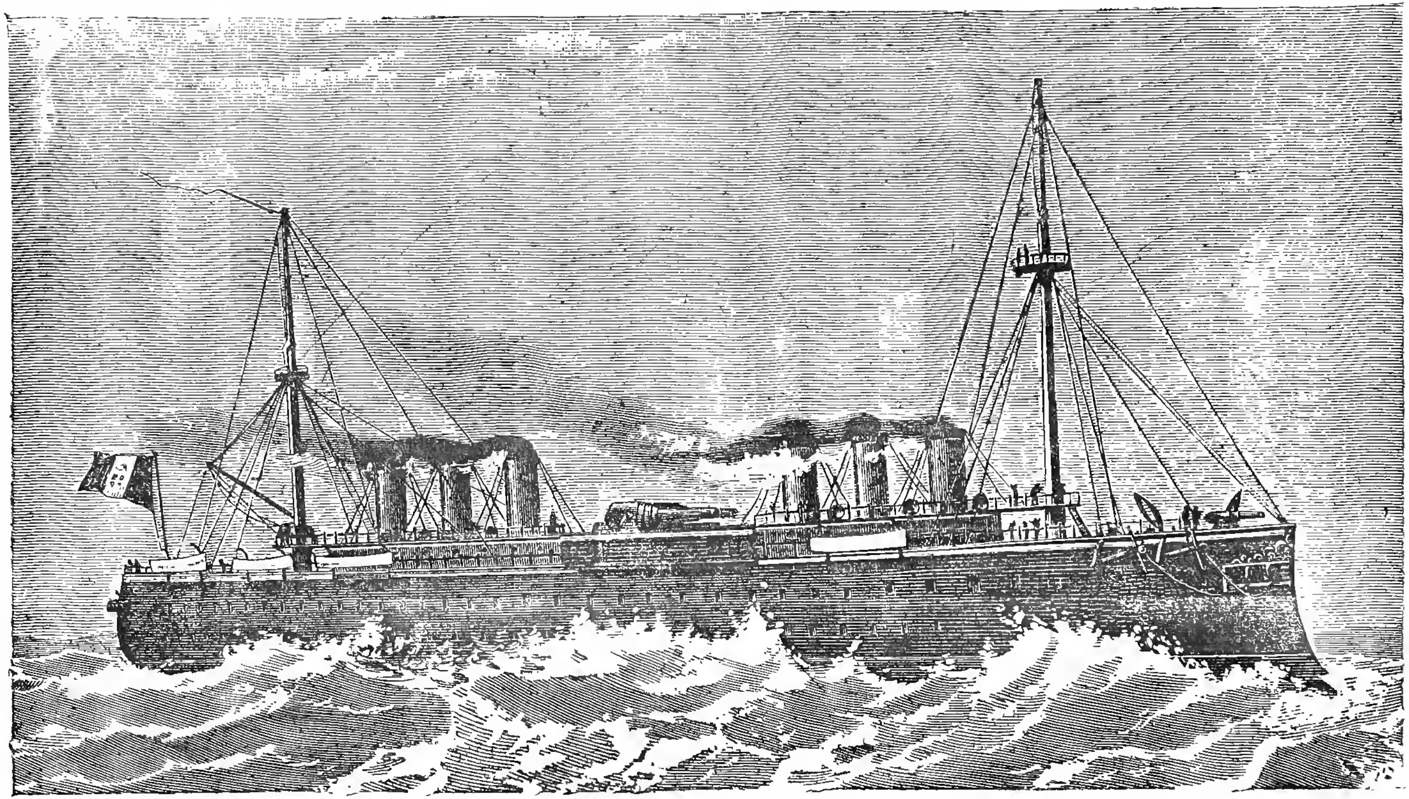


Fig. 5.



Figs. 5 and 6.

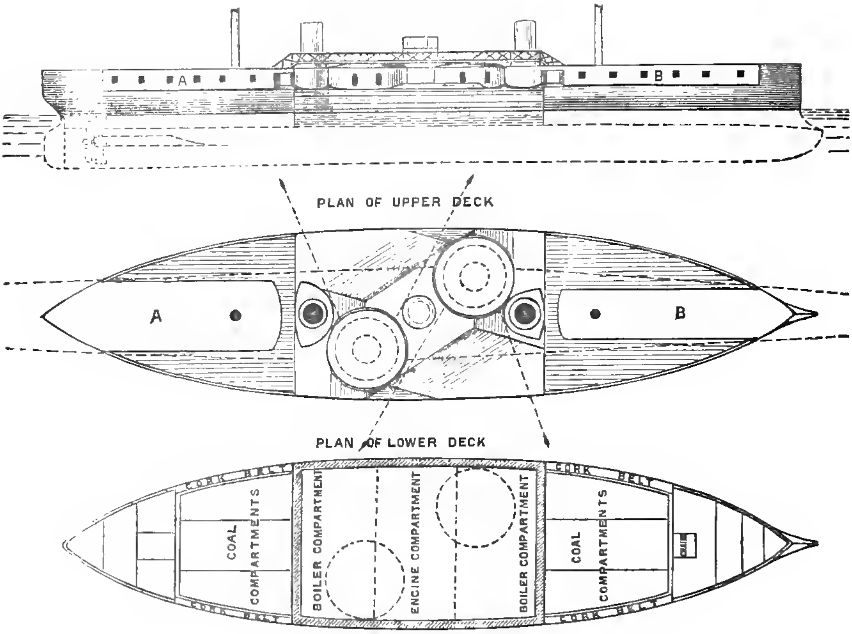
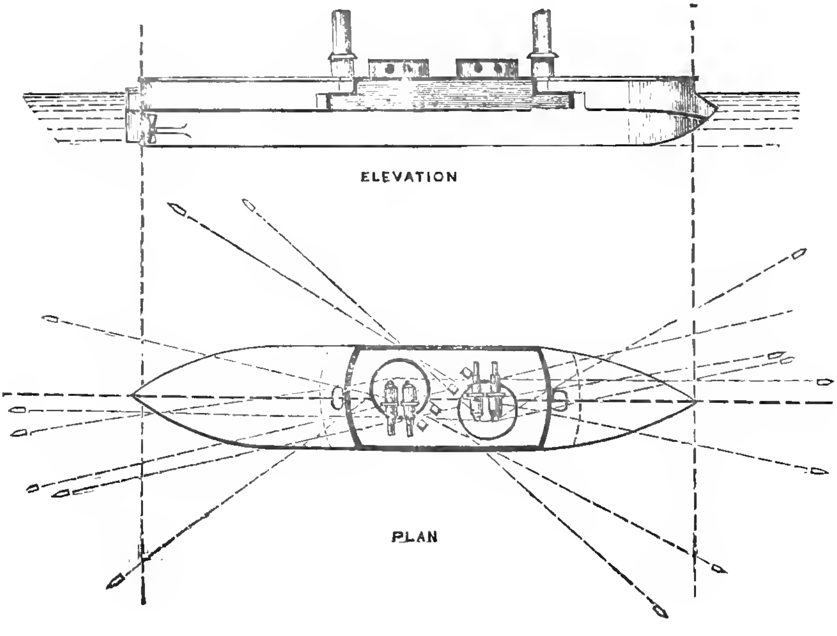


Fig. 7.



on *barbette* armour, and horizontal armour, are remarkable exceptions. The *Inflexible* (*vide* Figs. 5 and 6) *Duilio* (*vide* Fig. 7, p. 110) *Dandolo, Ajax, Agamemnon, Colossus,* and *Edinburgh,* are instances of citadel turret ships, and the *Admiral* class, (*vide Benbow,* Fig. 8,) of *barbette* citadel ships with unarmoured ends. The secondary attack would probably be adopted against such heavily clad vessels. On the other hand, such ships as the *Glatton, Dreadnought, Thunderer* (*vide* Fig. 9) and *Devastation,* are hardly open to any secondary attack. With regard to the

Fig. 8.

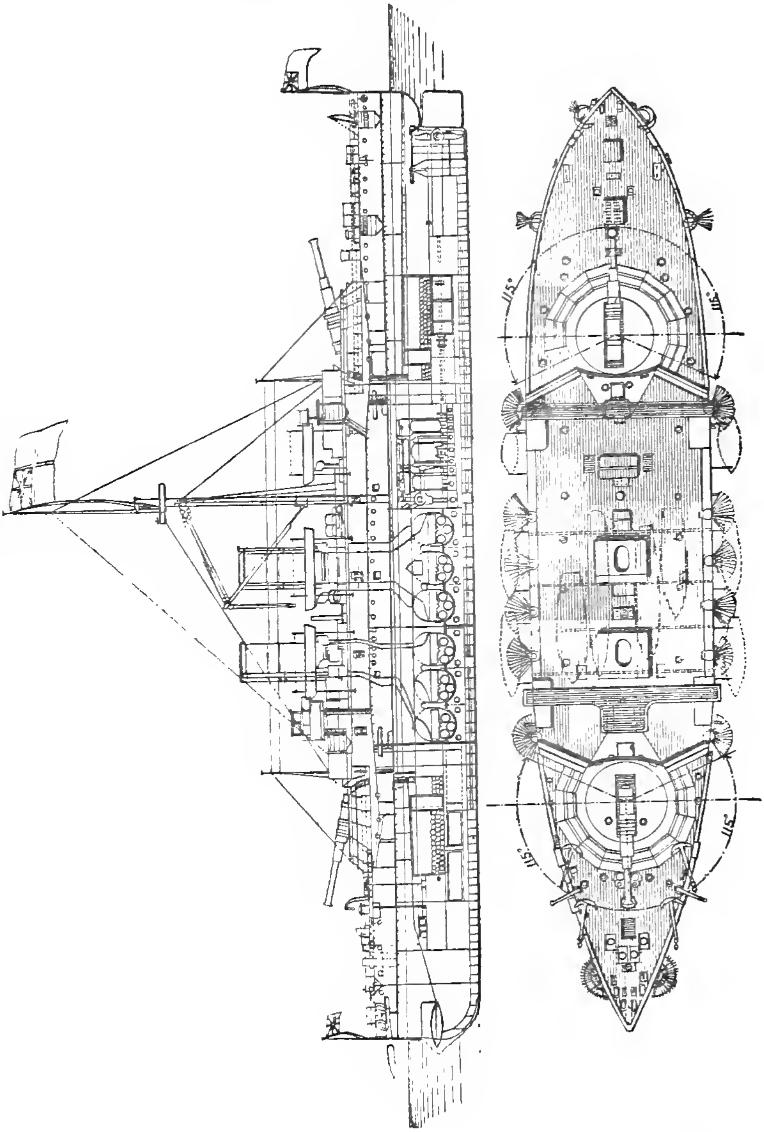
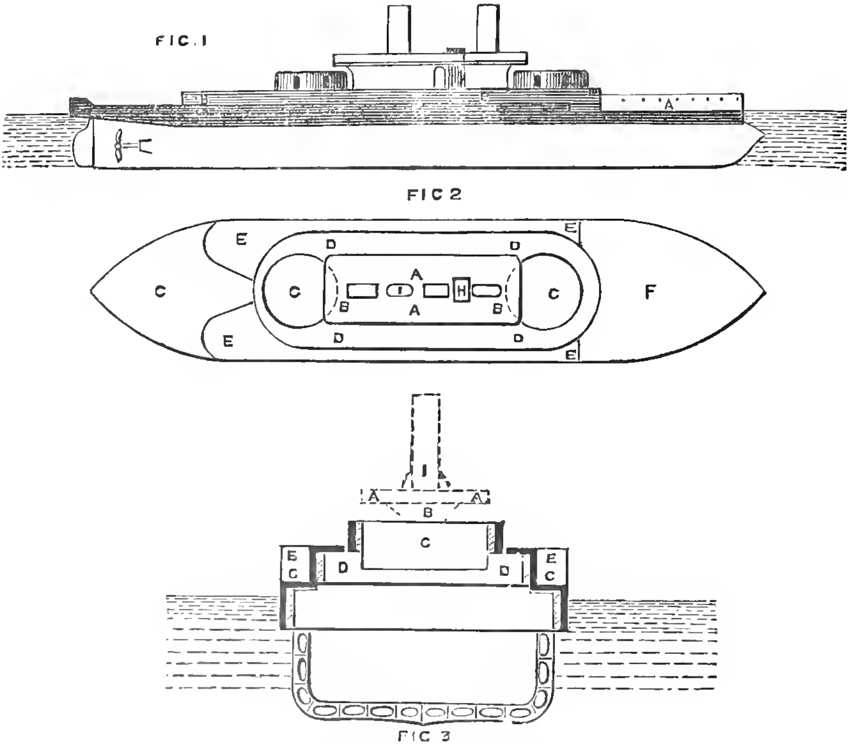


Fig. 9.



primary attack of the side armour, it is very important to know whether the ship is plated with iron, steel, or steel-faced armour. If iron it is useless to attack with projectiles that have not at least 1000 feet striking velocity for each calibre in the thickness of the armour. Thus a 12-inch gun requires at least 1000 feet velocity for each 12 inches, 1500 for 18 inches, and 2000 for 24 inches. As the ship is seldom exposed to a perfectly direct blow, the chance of heavy armour being perforated is small, and it would be as a rule useless to fire steel filled shells, and much more chilled-iron filled shells at thick armour, oblique impact almost always breaking shells up. If the armour is steel-faced or steel, the chance of perforation by a single blow is small in the most heavily plated ships, but continued fire may break up the armour. Guns which are no match for the armour, and would be useless against it if it were wrought-iron, may assist in breaking up hard armour in long continued fire. Altogether the primary attack of the side armour of heavily plated ships, unless made by guns of power far out-matching the armour when it is steel-faced or steel, can only be expected to be successful if the ship is exposed a long time to it. Wrought-iron is more liable to perforation, but bears the continued attack of guns that cannot perforate it specially well. The nature of the armour might influence the choice of guns employed in attack. This is most obvious if the forts as well as ships be taken into consideration. At the present time any foreign fleet lying off a foreign armoured fort, would furnish an example of the two kinds of armour, for the older ships would as certainly be clad in iron, as the forts would be covered with Grüson's chilled-iron armour. Wrought-iron must be perforated. Chilled-iron must be fractured. The former is effected by shot in proportion to their powers of perforation, the latter probably in proportion to their energy. What is especially liable to mislead, is the fact that gun's powers are generally estimated according to perforation. Speaking generally, the new type guns would display their powers best against ships, for though total energy and racking power has been increased in these guns, it has not been at all in proportion to the increase in power of perforation, because the small calibre assists perforation, but does not affect the question of total energy and total smashing blow.

Thus the older-fashioned guns might do better against forts than might be expected, while any smaller new-type guns would only display the full powers, with which they are generally credited, against ships or other structures covered with armour sufficiently soft to admit of perforation.

It appears to be generally recognised now that if ships are brought to anchor, they are subject to attack of their decks by mortar fire.[1]

It is hardly necessary here to discuss the ships that depend on their small size and powers of attack, and in which armour is dispensed with. They are sometimes protected from machine gun fire by steel shutters, as in the larger cruisers built at Elswick for China. Coal is utilized as far as possible, and the vital parts of the ship are kept below the water line. (For coal, *vide* p. 115).

Polyphemus

The *Polyphemus* can hardly be called an armoured vessel in the usual sense of the term, but she is covered with curved steel deck armour. The general figure of her structure in an incomplete state is shown in Figs. 10 and 11, p. 114. The entire "turtle back," to five feet below the water line, is covered with a Whitworth inch steel plate (45 tons tenacity). From 2½ feet below the water line the turtle back is further protected by Whitworth steel scales (*vide* Fig. 12) ten inches square and one inch thick, held by screws, as shown in figure (tenacity 65 tons); besides this plating she is constructed of double ½-inch ship-building steel of about 26 tons tenacity. The figures of the *Polyphemus* are not correct in all details, and are only intended to show the general form and character of the vessel.

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[1] *Vide* Meppen experiments, 1879, p. 94, Part I. Rifled howitzers have been supplied to our coaling stations.

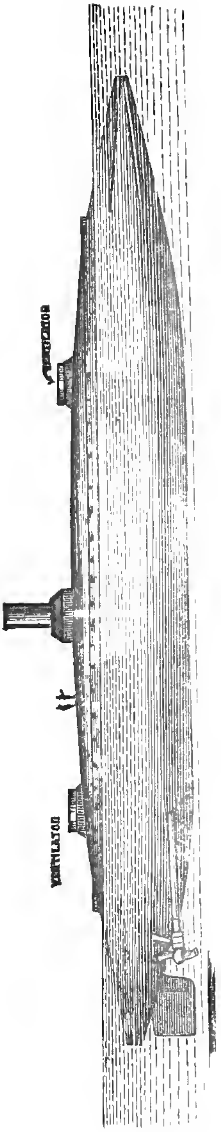


Fig. 10.

SIDE VIEW

Fig. 11.

VIEW FROM HEAD

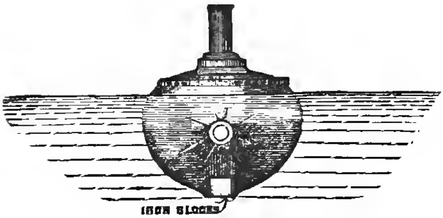
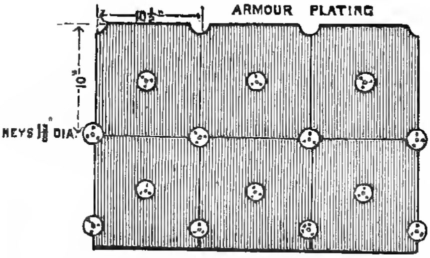


Fig. 12.



CHAPTER VIII.

COAL PROTECTION.

IN 1880, some experiments[1] were conducted by the Committee on Ordnance, of which the *late* General Gordon, C.B., was President, with a view to ascertaining the effect of shells on coal, in order to obtain data as to the defence of unarmoured ships, such as merchant vessels, and also as to the substitution of coal resistance for that of side armour in battle ships.

A coal target 60 ft. thick was used in order to represent the case of a ship filled with coal from side to side.

The 6-inch R.B.L. gun was employed at 100 yards range at coal without any fortification plates.

3 Palliser chilled shells filled with sand, fired with 32 lb. charges, penetrated from 16 to 18 feet, 2 broke up on impact.

1 common shell filled and fuzed, firing charge 34 lb. P., burst after penetrating 13 feet, striking velocity about 1850 feet.

2 common shell filled and fuzed, firing charge 25 lb. P., and one double shell, similarly fired, burst after penetrating about 9 feet.

Fortification plates $\frac{3}{8}$*-in. thick,* were inserted in the coal 3, 6, 9 and 12 feet from the front.

1 Palliser shell (weighted) firing charge 34 lbs. P., penetrated 3 plates, entering 12 feet into the coal and 11 inches into the ground, another, similarly fired, penetrated 4 plates and 17 feet of coal.

1 common shell filled and fuzed, fired with 25 lbs. P., burst at 6 feet penetration, passed through first plate, and blew a hole through second one.

1 double shell filled and fuzed, charge 25 lbs. P., burst at 8 feet, having passed through first and second plates, and made a hole in third plate.

1 double shell, similarly fired, burst at 3 feet, blowing hole in front plate, but not reaching second plate.

With fortification plates $1\frac{1}{2}$*-in. thick of mild steel,* 12 *feet from front,* no coal behind plates.

1 Palliser shell weighted, charge 34 lb. P., shell broke up, fragments stopped by plate.

1 Palliser shell filled with powder, charge 84 lbs.; shell apparently burst, fragments did not reach back plate.

Fortification plates, $1\frac{1}{2}$*-in. thick, mild steel, at* 5 *feet from front,* total depth of coal 15 feet.

1 Palliser shell (weighted) charge 34 lbs.; shell broke up. Plate broken, maximum penetration of fragments 10 feet.

1 Palliser shell (filled with powder) firing charge 34 lbs., plate broken; shell broke in two but powder charge not fired, total penetration 15 feet.

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[1] Not given in D. of A. Proceedings, but in a special report printed March 29, 1881.

The 8-inch B. L. gun was fired at 100 *yards with* 90 *lbs. P. charge.*

Without fortification plates. 1 Palliser shell weighted, penetrated 26½ feet, 1 common shell (filled and fuzed) burst after penetrating 15 feet.

With ⅜-in. fortification plates. 1 Palliser shell, weighted, penetrated 4 plates and 18 feet of coal.

With plates 1½-*in. thick, mild steel, at* 12 *feet from the front.*

1 Palliser shell (filled with powder) burst just in front of 1½-in. plate, blowing hole through this plate and the ⅜-in. skin behind it.

With plates 1½-*in. thick, of mild steel,* 5 *feet from the front.*

1 Palliser shell (filled) burst, plate broken, maximum penetration of fragments 12 feet, skin plate at 15 feet driven back 20 inches.

It was concluded that a 6-*in. Palliser shell* (blind) with 34 lbs. firing charge, which, at 100 yards, had a striking velocity of 1850 feet, penetrated about 18 feet.

Fortification ⅜-in. plates placed vertically amongst the coal had little effect, their tendency is to deflect the shot.

A 1½-in. plate of mild steel was equivalent to 3 feet in coal.

Bursting charges of common and double shell had no incendiary and little or no disruptive effect. Palliser shell filled were less effective than weighted with sand.

The 6-in. gun at 100 yards should perforate a solid unbacked plate of wrought-iron 10½ inches thick. This may be taken as equivalent to 18 feet of coal.

The penetrative power of 8-*inch Palliser* into coal with striking 1930 f.s. was about 26½ feet.

Four ⅜-in. plates reduced the penetration by about 8 feet.

If, as in the case of the 6-inch gun, a 1½-in. mild steel plate is equivalent to 3 feet of coal, the penetration with 1-inch plate should be about 23 feet.

The common shell produced no incendiary effect.

The 8-in. projectile at 100 yards should perforate 13½ inches of iron, this should be equivalent to 26½ feet of coal.

Conclusions and recommendations.

20 feet of coal without plates is proof against 6-in. projectiles at short ranges, or 17 to 16 feet if a 1½-in. plate be inserted. 30 and 25 feet respectively would resist the 8-in. gun projectiles. With less coal more plates must be used. Steel projectiles would probably act better than Palliser projectiles, a large proportion of which broke up. It might be desirable to imitate the conditions of an actual ship and

learn if the projectiles penetrate decks after deflection. Also the disruptive effect of large common shells and of steel shells charged with guncotton should be tried.

It may be seen from the above that, roughly speaking, 2 *feet of coal is equivalent to* 1 *inch of iron.*[1]

It is to be remembered generally that vessels depending on coal protection would be more vulnerable as their time at sea increases and their supply runs out.

CHAPTER IX.

RESULTS PRODUCED IN ACTION.

American experience

THE first engagement that occurred between armour-clad vessels of any class was that of the *Merrimac* with the *Monitor*.[2] The *Merrimac's* armour was inclined at an angle of 30° with the horizontal; it consisted of narrow bars of railway iron in two thicknesses, making a total of 3 inches, laid on 20 inches of oak. The *Monitor* fired 11-inch smooth-bores, with 15 lb. charges. Lieut. Very observes—"As far as can be ascertained, no material damage was done, nor should it have been expected." Had the 30 lb. charge been used during the action . . . . which doubtless would have been the case if the government practice had not so carefully excluded it, the muzzle-energy of the projectile would have been 2730 foot-tons or more than double what it was, and, as was afterwards proved by experiment, both in the United States and in Europe, every fair blow planted by the *Monitor* in the action would have smashed a hole.

On April 7, 1863, the *New Ironsides*, carrying $4\frac{1}{2}$ in. solid wrought-iron plates, backed by 21 inches of oak, took part in the general action with the Charleston forts. Captain Turner in his report says—"Forcing her way up the Channel, she received the fire of the enemy generally obliquely, excepting when she fell off one way or the other. One of these shots striking the forward facing of a port shutter, carried it away instantly . . . . the damage done to this ship, with the exception of the loss of a port shutter is not material. The distance at which she received the severest fire of the enemy is about 1000 yards."[3] It appears that the bolts were driven out by the impact of shot. The *New Ironsides* had a somewhat similar experience in an attack on Forts Wagner and Sumter on Aug. 16, and again on

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[1] How rough an estimate this must be is apparent from the fact that the resistances of plates are nearly proportional to the squares of their thicknesses, and that this is owing to mechanical reasons which cannot apply to the penetration of coal, the resistance of which must be probably nearly proportional to its thickness.

[2] Development of Armour, Very, p. 387.

[3] *Ibid.*, p. 391.

Sept. 10, 1863. Sand bags were found valuable on both occasions to prevent the flying of bolts and langridge. In a period of 6 months this ship was struck 193 times, and yet was never forced to go into port for repairs.

Numerous examples of the behaviour of ironclads of this date might be quoted from the report of actions in the American War. Speaking generally, it appears that injuries under the hottest fire hardly extended to more than the subsidiary parts of the vessel's armour, such as port-shutters, bolts, &c. Lieut. Very considers that evidence of weakness in laminated armour was ignored or slurred over. Captain (now Admiral) Simpson says—"The solid plates of hammered iron on the *New Ironsides*, though only 4½ inches in thickness, resist the impact of shot much better than the 5 inches of laminated iron on the sides of the monitors." "The laminated iron when disposed in a plane perpendicular to the flight of the projectile, does not seem to answer all demands; but when disposed in the form of a turret, no objection can be raised to it. The turrets are as near impregnable as any thing can be made. The only objection to them is the 'through bolts," which allow the nut to fly when the head of the bolt is struck." The most vital and dangerous part of this construction is the roof of the turret, which must be apparent to every one as weak. It can never be struck without causing damage. The roof of the *Weehawken* was struck at long range; the result was the fracturing of the thigh of one man and lighter wounds to two others.[1] Captain Simpson wrote a remarkable report on the evil of turret pilot house and spindle system in October, 1863, strongly recommending the base ring and anti-friction roller system long since adopted in England.

In February, 1868, during the war between Brazil and Paraguay the Brazilian monitor *Alagoas* was put to a very severe test; she carried on her sides 4½ inches solid wrought-iron plates backed with 15 inches of teak, and a ½-inch skin. Her turret carried 6-inch solid plates backed by about 10 inches teak and two ½-inch skin plates.[2] "In an attack on some Paraguayan batteries she was struck 200 times, her side armour being pierced 12 times and her turret twice. The armament of the batteries consisted of Whitworth 32-pr. rifles, 68-pr. and 120-pr. smooth-bores, and the range for the greater part of the time was less than 100 yards. The turret was very badly damaged; nearly all the bolts being broken, and the wood backing being badly crushed in several places."

Huascar actions.

In October, 1879, took place the fight between the Peruvian vessel, *Huascar*,[3] and the Chilian ships *Blanco, Encalado* and *Almirante Cochrane*. The *Huascar* was a single turret vessel, carrying 4½-inch iron armour, tapering down to 2 inches at bow and stern, backed by 10 inches of teak, and a ⅝-inch skin. Her turret had 5½ inches iron (solid),

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[1] Development of Armour, Very, p. 413.

[2] Development of Armour, Very, p. 437.

[3] The engagement between the *Shah* and the *Huascar* does not concern the purpose of this work further than to illustrate the bare fact that it is difficult to strike an adversary a full blow under the condition of an actual running fight and to show the effect of a common shell.

13 inches teak, and ½-inch skin. Her conning-tower had 3-inch plates, backed by 8 inches teak, with two ½-inch skin plates of iron. The *Huascar*[1] having higher speed than any Chilian iron-clad vessel, had proved herself such a scourge, that the Chilian supplies had been cut off to a considerable extent. On May 21, 1879, she mercilessly riddled with shot, and rammed the unarmoured Chilian ship *Esmeralda,* one of whose boilers had been blown up, and who was almost drifting about. The Captain, Captain Pratt, and part of the crew of the *Esmeralda* desperately attempted boarding on the two occasions when the *Huascar* rammed her, but the boarding parties were overpowered and slain, and she sank with nearly all her gallant crew, with her colours still flying.

To capture the *Huascar* the Chilians had cleaned and repaired the *Cochrane,* and had improved her rate of speed so that she was at least as fast as the *Huascar.* Two divisions were formed, one led by the *Blanco,* and the other by the *Cochrane,* which were sister ships, carrying 9 inches of armour, and 12½-ton 9-inch guns. The *Blanco* and two other ships found the *Huascar* and another Peruvian vessel, and drove them north into the path of the *Cochrane,* and two fast unarmoured ships. Captain Grau, commanding the *Huascar,* tried to pass north-east of the *Cochrane,* but was cut off and exchanged shots while the *Blanco* was above four miles astern. It is now difficult to trace the exact course followed by the ships,[2] but it appears that the *Huascar* so far turned away from the *Cochrane* as to receive a most destructive fire from her heavy guns firing ahead, while the *Huascar's* fire was masked by her poop. A 9-inch Palliser shell from the *Cochrane* partly destroyed the conning-tower of the *Huascar,* killing Captain Grau and disabling the steering wheel. A similar shell penetrated the turret, killing most of the detachment, and a third entered the Captain's cabin, and destroyed the steering tackles and some men trying to work them. Now the *Blanco* came up and endeavoured to ram the *Huascar,* but passed astern of her, turning the *Cochrane* off her course, and causing her to make a complete circle to avoid collision. About the middle of her circle, a large shell, believed to have come from the *Blanco* by mistake, passed completely through the *Cochrane* abaft her battery, which, though it did not burst, did much damage, killing 2 and wounding 8 men. The *Huascar* was too far damaged to be able to avail herself of this opportunity to escape. The Chilian ironclads fired incessantly at her, their Nordenfelts cleared her deck, and "silenced the Gatling on her top. Another shell penetrated her turret, and bursting, splashed the left gun, killing the first officer and the men who were working it." The *Huascar's* steering tackles were destroyed a third time, and she soon after hauled down her flag.

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[1] This is chiefly taken from Lieutenant Madan's spirited account in U. S. Institution Proceedings, 1881, No. CXII., p. 695. For *Cochrane, vide* fig. 3, p. 107.

[2] *Vide* also King's War Ships and Navies of the World, p. 439, and Development of Armour, by Very, p. 438. King states that the *Huascar* kept her stern purposely away from the enemy, while Madan blames the Captain for not doing so. King states the Captain of the *Huascar* endeavoured to ram the *Cochrane,* and also that the remains of the crew repulsed an attempt of the Chilians to board and complete their capture.

Both the Chilian vessels fired Palliser filled shells. Out of 76 rounds from the 9-inch guns, and about 40 from lighter pieces, about 25 appear to have been effective hits, at least 16 of them being made with the 9-inch projectiles. The *Huascar* fired about 40 rounds with very little effect, only 3 striking the *Cochrane*, and inflicting no serious damage. The *Blanco* was untouched. Lieutenant Madan, R.N., who obtained his information from Chilian and Peruvian Officers, observes that "the weak armour of the *Huascar* appears to have been worse than useless, as although it deflected three or four 9-inch shells, and resisted the smaller projectiles, yet it enabled the Chilians to dispense with fuzes and use Palliser shell, which burst, after penetrating, with terrible effect."

By the rule of thumb, it may be seen that the 9-inch shot, even with 1300 feet velocity would be able to perforate about $\frac{9 \times 1300}{1000} = 12{\cdot}7$ inches of iron unbacked. It is evident therefore that up to the glancing angle these shot would perforate the armour of the *Huascar*, and the result was what must have been expected in any regular attack as far as the *Huascar's* armour was concerned. It might have been expected that at close ranges, the *Huascar* might have damaged the *Cochrane*, but not when running from her and striking her obliquely.

Effects of fire on *Huascar*.

Lieut. Madan enumerates the following injuries to the *Huascar*:—

(1.) Palliser shell entered forecastle, wrecked it, and broke stem.[1] (2) Carried away capstan. (3) Palliser shell glanced on turret, cutting a groove 1 inch deep. (4) Palliser shell entered turret compartment below upper deck on port side, burst over magazine hatch, choked turret machinery with *debris*, but it did no material damage, as it revolved easily afterwards. (5) Palliser shell struck edge of upper deck and burst, splashing turret with fragments. (6) Palliser shell entered turret to right of right gun, and struck right carriage bracket, and burst, killing, it is said, all men in turret. The gun might still have been fired perhaps with one capsquare, but it ceased firing. (7) Palliser shell entered turret to right of right gun near top, burst and struck left gun, injuring but not disabling it, and killing or wounding all the crew it is said. (8 and 9) Struck and destroyed conning-tower (3 ins. iron and 10 ins. backing) No. 8 disabled fighting wheel below. (10) Palliser shell glanced on funnel. (11) Palliser shell entered engine room, bursting, and killing 4 men on upper platform, but did not damage engines or men in charge. (12) Palliser shell struck a 12-pr. upper deck gun, knocking off muzzle. (13) Palliser shell burst inside officer's cabin. (14) Palliser shell entered poop. (15) Palliser shell burst in stern, cutting rudder chains, and killing men. (16) Palliser shell burst in stern, injuring stern post and killing all men on relieving tackles. There were many minor injuries.

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[1] These numbers are taken from bows to stern, not in their order of time. Lieutenant Madan obtained his facts from Chilian and Peruvian Officers, especially from the senior executive Officer of the *Cochrane*.

NAVAL ATTACK OF ALEXANDRIA FORTS.[1]

The attack of the forts of Alexandria in 1882 should be studied in works specially devoted to it, such as the English and American official reports. Major Walford, R.A., read a very full paper on it at the United Service Institution.[2] Before discussing it briefly here, it is well to make one or two remarks as to its general character. First, it must be clearly understood that the case is not considered as an instance of a fight between ships and really powerful sea forts. A thoroughly well defended harbour would have mines laid down, rendering the movement of ships dangerous. The water would, perhaps, be divided up into imaginary squares, and mechanism might be provided for automatically directing guns on each spot. Possibly ships engaging at anchor might be assailed by rifled mortar or howitzer fire. Torpedo boats might also be encountered. In some cases there might be batteries on positions with high command. The existence of such elements would make an attack by sea a very serious matter, undoubtedly such an operation as would need special reasons to justify it.

In the case of Alexandria these dangers were not present, but complications and difficulties were not wanting; for example, circumstances demanded that the ships should be sparing of ammunition. The action was fought under conditions rendering it very difficult to distinguish the features of the forts, and to direct the fire to good purpose.

Moreover the vessels, with the exception of the *Inflexible,* were by no means the most heavily clad or powerfully armed possessed by England. The *Thunderer* class was wholly unrepresented.

The attack should be regarded, then, not as generally representative of what might occur, but as an important naval operation of a special kind whose complete success justified the judgment and skill with which it was conducted.

Certain British ships, the *Invincible, Monarch,* and *Penelope,* had been lying in the inner harbour of Alexandria up to July 10th, and they then moved into position in the outer harbour (*vide* plan, Pl. XIX.). To this may be perhaps attributed the fact that the Egyptians laid down no submarine mines, for it appears that they had an abundant supply of them, although only a limited quantity of cable was found. The general character of the attack may be seen from Lord Alcester's orders, which were as follows :—

"There will be two attacks. (1) From the inside of the harbour, in which the *Invincible, Monarch,* and *Penelope,* will take part. (2) By the *Sultan, Superb, Temeraire, Alexandra,* and *Inflexible,* from outside the breakwater." . . . . "On the batteries opening on the off-shore squadron in reply, every effort will be made by ships to destroy the batteries on the Ras-el-Tin Peninsula, especially the light-house battery bearing on the harbour. When this is accomplished, the *Sultan, Superb,* and *Alexandra,* will move out to the eastward, and attack Fort Pharos, and, if possible, the Silsileh battery. The

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[1] Extracted from Lord Brassey's Naval Annual, 1886.

[2] *Vide* U. S. Institution Proceedings, 1883, Vol. XXVII., No. CXIX.

Inflexible will move down this afternoon to the position off the Corvette pass assigned to her yesterday, and be prepared to open fire on the guns in the Mex lines in support of the in-shore squadron when signal is made. The *Temeraire, Sultan,* and *Alexandra* will flank the works on Ras-el-Tin. The gun-vessels and gunboats will remain outside, and keep out of fire until a favourable opportunity offers of moving in to the attack of Mex."

The strength of the ships and forts that were to be thus engaged may be seen generally from the following Tables :—

Ship's Name.	Displacement in Tons.	Guns.									Armour. Maximum.	Draught of water
		80-ton 16-in.	25-ton 12-in.	25-ton 11-in.	18-ton 10-in.	12-ton 9-in.	9-ton 8-in.	6½-ton 7-in.	64-pr.	40-pr.		
											inches.	feet.
Inflexible (Turret)	11,400	4	—	—	—	—	—	—	—	—	24 to 16	25$\frac{5}{12}$
Monarch (Turret)	8,320	—	4	—	—	2	—	1	—	—	10 to 8	26
Temeraire (Barbette)...	8,540	—	—	4	4	—	—	—	—	—	11 to 8	27⅙
Alexandra..................	9,490	—	—	2	10	—	—	—	—	—	12 to 8	26½
Sultan	9,290	—	—	—	8	4	—	—	—	—	9 to 6	27½
Invincible..................	6,010	—	—	—	—	10	—	—	4	—	8 to 6	22¾
Superb	9,100	—	—	—	16	—	—	—	—	—	12	26⅙
Penelope	4,470	—	—	—	—	—	8	—	—	3	6 to 5	17½
Total Guns... ...		4	4	6	38	16	8	1	4	3		

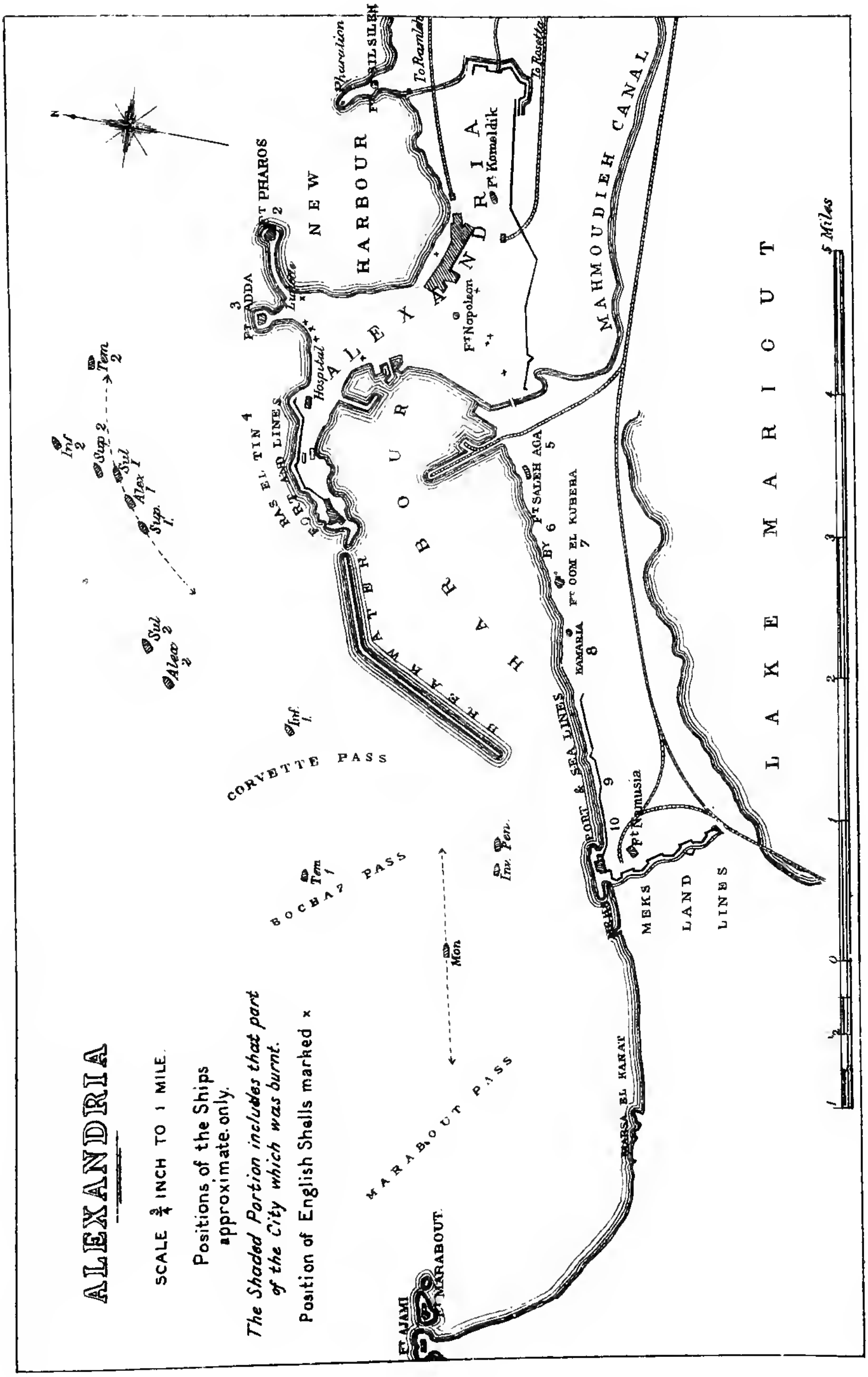
The batteries of Alexandria had the following armaments :—

RIFLED GUNS.

Forts and No. on Plan.	Mounted.					Unmounted.		Total.
	10-in. M.L.	9-in. M.L.	8-in. M.L.	7-in. M.L.	40-pr. B.L.	10-in. M.L.	9-in. M.L.	
Silsileh (1)	—	1	1	—	—	—	2	4
Pharos (2)	1	3	2	—	2	—	—	8
Adda (3)	1	3	1	—	—	—	—	5
Ras-el-Tin Lines } (4)	1	3	2	2	1	—	—	9
Ras-el-Tin Fort... } (4)	1	4	1	—	—	—	—	6
Oom-el-Kubeba (7) ...	—	—	2	—	—	—	—	2
Mex Fort (10)	1	1	3	—	—	2	4	11
Total	5	15	15	2	3	2	6	45

Mounted Rifled Guns in all ... 37 Unmounted Guns ... 8

Pl.XIX.


ALEXANDRIA
SCALE 3/4 INCH TO 1 MILE.
Positions of the Ships approximate only.
The Shaded Portion includes that part of the City which was burnt.
Position of English Shells marked ×
N
NEW HARBOUR
ALEXANDRIA
HARBOUR
BREAKWATER
MAHMOUDIEH CANAL
LAKE MARIOUT
Ft PHAROS 2
Ft ADDA 3
RAS EL TIN 4
FORT AND LINES
Ft SALEH AGA 5
BY 6
Ft OOM EL KUBEBA 7
KAMARIA 8
FORT & SEA LINES
9
10
Ft Kamusia
MEKS LAND LINES
MEKS
MARSA EL KANAT
Ft MARABOUT
Ft AJAMI
Ft SILSILEH 1
Pharos
Lunatic
Hospital
Ft Napoleon
Ft Komeldik
To Ramleh
To Rosetta
CORVETTE PASS
BOGHAZ PASS
MARABOUT PASS
Inf 2
Sup 2
Sul 1
Alex 1
Sup 1
Tem 2
Sul 2
Alex 2
Inf 1
Tem 1
Inv.
Pen.
Mon
5 Miles
4
3
2
1
0
1

SMOOTH-BORE GUNS AND MORTARS.

Fort or Battery and No. on Plan.	Guns.			Mortars.				Total S. B. pieces.
	15-in.	10-in.	6·5-in.	20-in.	13-in.	12-in.	11-in.	
Fort Silsileh (1)	—	3	—	—	1	—	—	4
〃 Pharos (2)	—	6	31	—	4	—	—	41
〃 Adda (3)	—	14	—	—	5	—	—	19
Ras-el-Tin Lines (4)..	4	15	11	1	6	1	2	40
Fort Ras-el-Tin	2	5	21	—	1	—	2	31
〃 Saleh Aga (5)......	—	4	8	—	—	—	—	12
Battery (6)	—	2	2	—	—	—	—	4
Fort Oom-le-Kubeba (7)	—	6	10	—	1	1	—	18
〃 Kamaria (8)	—	2	3	—	1	—	—	6
Mex Sea Lines (9)	4	11	9	—	—	—	—	24
〃 Fort (10)	—	4	5	—	3	2	—	14
Mounted S. B. Guns in all ...		182		Mounted Mortars ...		31		213

It may be seen from the above Tables that while the guns of the fleet were much more powerful than those of the forts, some of the latter might, under reasonably favourable circumstances, perforate the armour of all the ships except the *Inflexible*.

The guns and projectiles were supplied from Elswick, and correspond to the service old type Woolwich M. L. armaments carried by the British vessels.

On the morning of July 11th, 1882, at about 7 a.m., the British fleet opened fire in the order detailed by Lord Alcester. The position of the ships may be seen approximately in the plan.

The *Invincible* (flagship) and *Penelope* engaged at anchor in the outer harbour against the earthworks at Fort Mex at 1500 yards range. The *Monarch* acted with them under steam against Forts Mex and Oom-el-Kubeba, as well as eleven gunboats. The *Temeraire* supported the attack from the central pass into the harbour at about 4000 yards range, and the *Inflexible* in the Corvette pass divided her fire between earth and masonry forts, Oom-el-Kubeba at 4000 yards, and Ras-el-Tin at 2700 yards. The *Alexandra, Superb,* and *Sultan,* engaged all forts between Ras-el-Tin and Pharos, chiefly, at first under steam, at from 1500 to 2000 yards, and at length anchored at about 2200 yards distance. The gunboats, *Helicon, Condor, Beacon, Bittern, Cygnet, Decoy,* assisted as opportunity offered.

At about 10.30 a.m., Ras-el-Tin and Mex Forts were to a great extent silenced, and the *Alexandra, Sultan* and *Superb* attacked the centre battery and other forts farther to the east, the *Inflexible* and

Temeraire coming round and joining in the work. The *Superb* attacked Adda; the *Temeraire,* Pharos; and the *Inflexible,* both these forts. A shell from the *Superb* blew up the magazine in Adda, and silenced it about 2 p.m. The *Monarch* had silenced Oom-el-Kubeba about 1 p.m. The *Temeraire, Inflexible,* and *Superb,* silenced Fort Pharos about 2.30 p.m., and the centre battery ceased to reply to the *Sultan* and *Alexandra* about the same time. A battery at Hospital or Bluff Point was the last one silenced at about 3 p.m. At about 1 o'clock a party in a boat very gallantly landed and destroyed the guns in Fort Mex.

Effect of fire on forts.

The effect of the ships' fire on the various works was as follows:—

Fort Silsileh (not much engaged), a regular fort, chiefly earthwork, suffered little damage.

Fort Pharos, masonry with casemates, suffered severely, casemates riddled and choked. Three guns and carriages wrecked and others choked. One gun on the reverse face carried away and thrown on to its muzzle in the ditch 30 ft. distant. The rifled guns were silenced before the smooth-bores in the casemates, although the loss of life in the latter must have been out of all proportion to that in the former.

Fort Adda, earth revetted with masonry. Parapets cut about but not materially injured. Three guns struck and put *hors de combat.* The fort was wrecked by the explosion of the magazine, otherwise it might have continued firing.

Ras-el-Tin Lines (from Hospital Battery to Ras-el-Tin Fort). Masonry and earth. No guns actually disabled although struck; several put out of action by being dismounted; or by the carriages being broken, or choked with *débris.*

Ras-el-Tin Fort (masonry and earth, but with thin parapets). All rifled guns fairly put out of action, either by fire of the fleet or by accident. This fort fought better and suffered more than any other. The parapets were much cut about and buildings riddled.

Fort Saleh Aga an insignificant work, but with a command of 60 feet. One S. B. gun dismounted.

Fort Oom-el-Kubeba 80 ft. command, masonry and earth, with good profile. Parapet suffered much from *Inflexible* 80-ton gun shells. One gun destroyed.

Fort Kamaria untouched, probably did not engage in action.

Mex Sea Lines, about 25 feet highest command; guns firing *en barbette* over earth parapets, 15 to 18 feet thick. One or more guns dismounted by fire of ships.

Mex Fort, 22 feet command; guns *en barbette*; earth parapet unrevetted; parapets hardly injured, but buildings almost swept away. Three guns struck by shells and put out of action, and others by machine gun or shrapnel bullets. Two 10-inch guns received great protection from a wall some distance in front, which caught shells aimed at the guns; both the latter were struck, but not materially injured.

Fort Marsa-el-Kanat had no defensive power. Fort Marabout was attacked by gunboats. No guns were dismounted.

Effect of fire on ships.

The ships received the following injuries :—The *Inflexible,* penetrated in unarmoured parts, and a good deal knocked about aloft. *Monarch* and *Temeraire* untouched. *Alexandra,* struck sixty times, but not seriously injured. *Sultan, Invincible,* and *Superb,* armour indented, and minor injuries sustained.

The *Penelope* hulled eight times, but no serious injuries caused. A small slice cut off one gun near the muzzle.

Conclusion.

The *American Official Report,* written by Lieut.-Commander Goodrich, contains among other conclusions—

American report.

(1) Command is important for forts. (2) 30 feet of earth stops all projectiles. (3) Embrasures should be cut deep below crest. (4) No guns should be mounted *en barbette.* (5) Guns should be painted the colour of the works. (6) The value of armour has been under-rated. (7) Modern guns with flat trajectories are not the best for attacking earthworks. (8) Some ships should carry howitzers. (9) Vertical fire should be studied. (10) Disappearing guns firing *en barbette* are very efficient. (11) Ships gain more in accuracy by anchoring than they lose in increased exposure to injury. (12) The swell told against the shooting, especially of ships engaging broadside on. (13) Shot not aimed at guns or magazines are thrown away. (14) Vessels do not fight on even terms with forts. (15) Forts could not stop ships. (16) The forts might have been repaired and action continued.

Mj. Walford

Major Walford, R.A., forms conclusions agreeing with some of the above, and points out the advantage of counter-guards in advance of batteries, also of traverses, parados, and mantlets, and the evil of stone and brick in batteries. He recommends guns being strongly pivoted, well forward.

The additional suggestion may perhaps be made, that forts might mask or reserve their most powerful guns until they had drawn a large quantity of the ships' ammunition. It would be difficult for a fleet to detect such a practice, and the masked guns might obtain a better opportunity of damaging ships, if the latter became emboldened to draw in to closer range.

Admiral Le Hunte Warde.

Special causes, as noticed before, made accurate firing from the ships almost impossible. The conditions of sunlight and of the works made it very difficult to distinguish the guns and objects aimed at. Admiral Le Hunte Warde, who commanded the *Superb,* states that while the vessels were in motion, it was necessary, as fast as the smoke cleared, to identify objects aimed at from a new point of view, and then to fire at them at an altered range. So difficult was this, that to deal effectually with the forts it was judged necessary to anchor.

EXPLANATION OF DIAGRAMS SHOWING PERFORATION OF ARMOUR.

THE accompanying diagrams Pl. XVI., XVII., XVIII. and XIX., appeared in Lord Brassey's Naval Annual, 1886, and with his permission are here given. They are based on a series that owe their origin to the official one prepared by Colonel Noble in 1873.[1] Foreign ships were given by Captain Grenfell, R.N., in *Engineering*, and have been shown for some years past in the Austrian *Marine Almanack* as well as in the *British Navy*. To give to these diagrams a definite practical character, the following course has been followed:—

On the supposition that 3000 yards is the maximum range at which side armour will be systematically attacked, all projectiles perforating up to 3000 yards are shown with a clear blank hole. For every perforation effected only at shorter ranges the limit of range is entered in or near the hole. Thus, any officer finding armour corresponding to that of his enemy with a blank hole opposite his gun on the diagram, may hope to perforate *with a direct hit* at least up to 3000 yards. Should he find a number less than 3000 yards entered, he must not expect to perforate beyond the range so entered.

The armour is wrought-iron. It is only approximately representative. The types are chiefly French. The perforation includes backing and skin.

Colonel Maitland's diagram has been used for calculating loss of velocity at each range. On service each hit would have less power to perforate than is indicated on the diagrams in proportion as it strikes more obliquely.

The diagrams must be regarded as only approximate. They may however be of practical value, for an officer may be able to see at a glance that some ships armour is *well within the power of his guns* or *quite beyond them*, and behave accordingly.

On this, *vide* Remarks on Armoured Structures—Ships, pp. 103–113, Part II.

All armour clad vessels built prior to 1876, and many subsequently, are *iron* plated. To these the above directions apply. For example, suppose 10-in. M.L. guns to attack the French vessel *Redoubtable*, carrying 14-in. plates along her water-line, and 9½-in. plates on her central battery, the above rule would indicate that it would be useless to attack her water-line with less than 1400 ft. striking velocity, and her battery with less than 950 ft. Now the 10-in. 18-ton M.L. gun has has a muzzle velocity of a little over 1364 ft., and even if by a special charge it were brought up to 1500 ft., it would be right for such guns, even at the shortest ranges, to attack the central battery and not the water-line, for something must be allowed for backing, probable obliquity of impact, and range. The *Redoubtable*, like some other French ships, has an unarmoured battery which might be attacked by any ordnance.

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[1] The diagram prepared by the Author in 1872 was in a different form.

The question may naturally be asked why ships clad in steel and compound armour are treated as if only sheathed in the same thickness of wrought-iron. The reply is that the object is to furnish a low limit for guns available for attack. Steel varies much in quality. Some ships are known to carry very soft plates approaching wrought-iron more or less in quality. Hard steel could not be perforated at all but might gradually yield by fracture. In either case it seems unwise to lay down an arbitrary limit, and the only definite limits that present themselves are the high and low standards of attack adopted in experiments both for steel and steel-faced armour (*see* p. 37). The low one appearing to represent the low limit of useful attack here sought.

Thus it should be borne in mind, that while steel and steel-faced armour might be attacked about the limit shown in these diagrams for iron of the same thickness, they would not be perforated at all events at the same limit, but would probably yield more gradually and more or less by fracture.

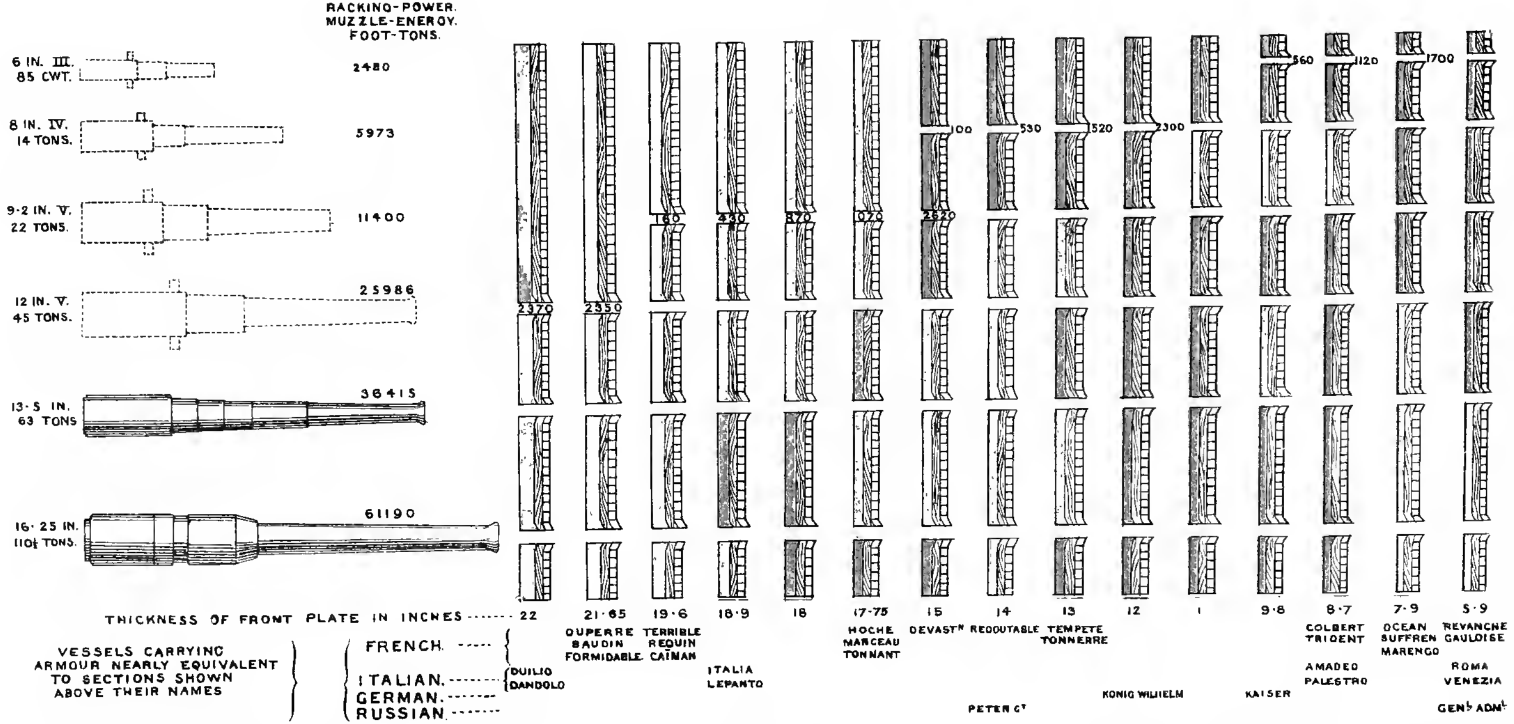
Oblique Perforation.

It may be readily seen by drawing a figure, that if a projectile perforates a plate at any angle θ with its face, its path through the plate multiplied by sin θ is equal to t, the thickness of the plate. Thus a shot which would perforate a 10-inch plate directly (*i.e.* at 90°) would, striking at 60° with the face, only perforate a plate $10 \times \sin 60^\circ = 8{\cdot}66$ inches thick.

Practically this calculation is seldom useful because the angle of incidence is seldom known, so that the maximum effect possible (*i.e.* direct perforation) is more important. In a siege, however, oblique perforation might be required.

BRITISH B.L. GUNS.

PERFORATION



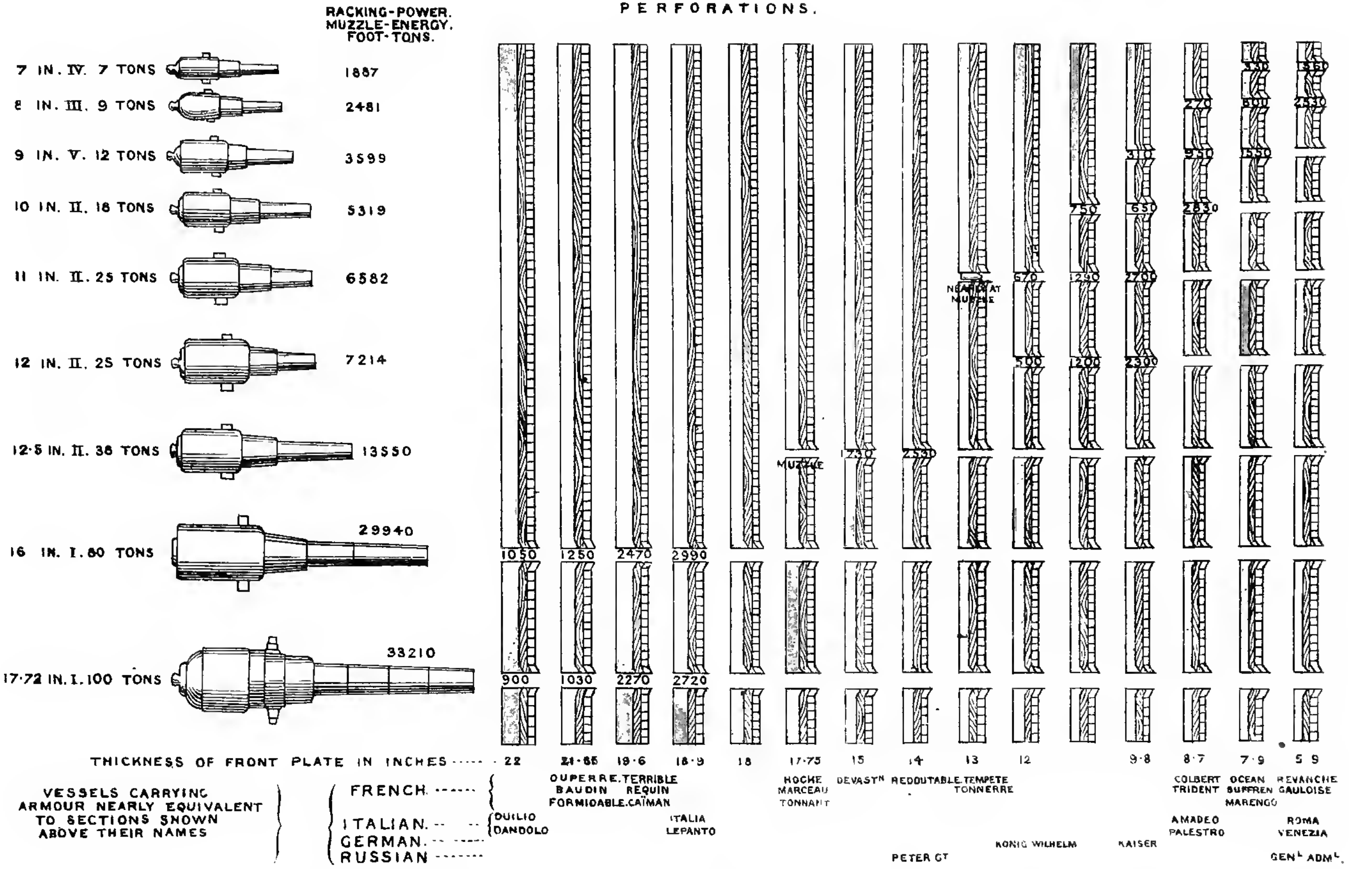
A HOLE WITHOUT FIGURES MEANS PERFORATION UP TO 3000 YARDS: MAXIMUM RANGES OF PERFORATION LESS THAN 3000 YARDS ARE MARKED IN FIGURES.

SCALE – 20 FEET TO AN INCH. SHADED GUNS ARE CORRECT IN GENERAL OUTLINE, DOTTED GUNS ONLY AS TO LENGTH.

ALL BACKING IS 18 IN. OF WOOD WITH 1½ IN. SKIN.

BRITISH M.L. GUNS.

PERFORATIONS.



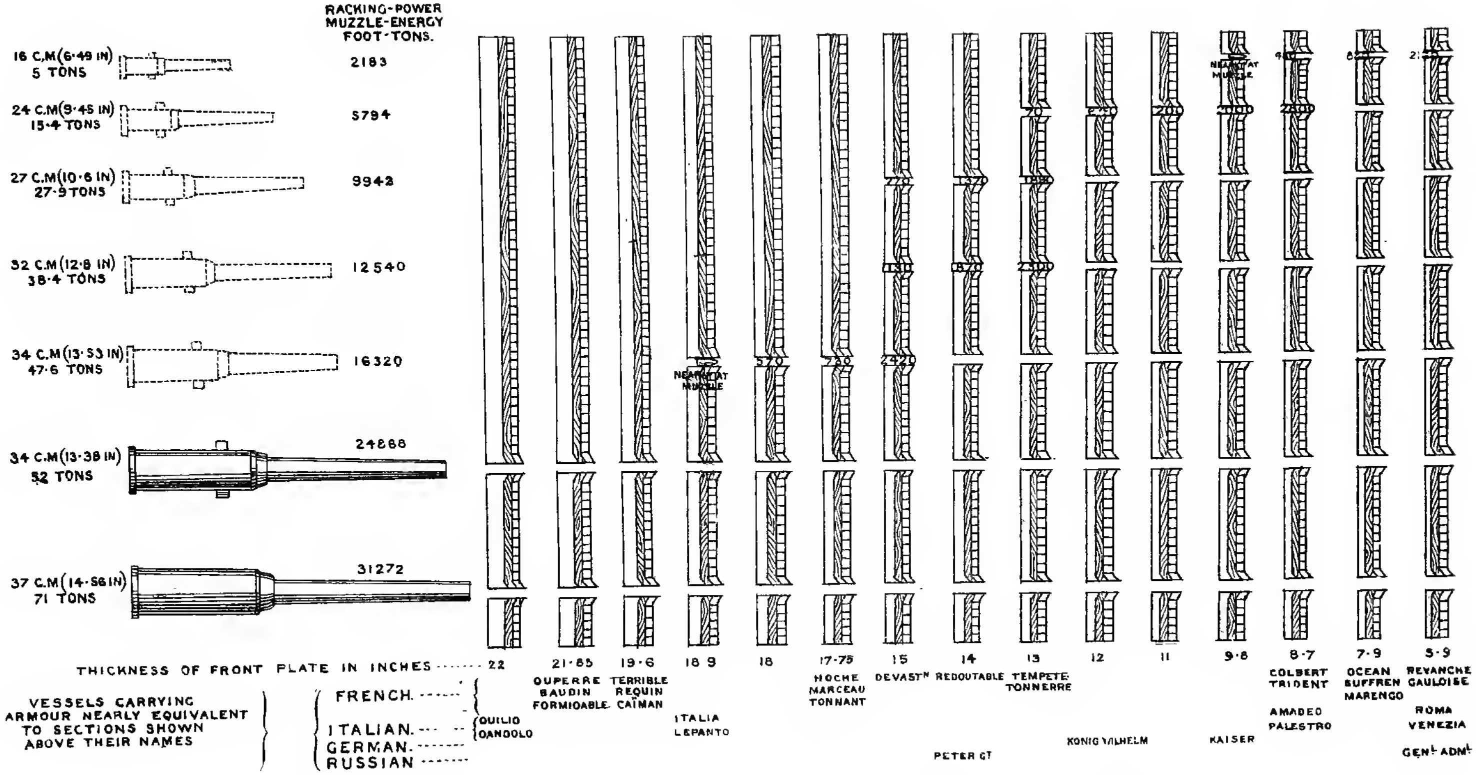
A HOLE WITHOUT FIGURES MEANS PERFORATION UP TO 3000 YARDS: MAXIMUM RANGES OF PERFORATION LESS THAN 3000 YARDS ARE MARKED IN FIGURES.

SCALE - 20 FEET TO AN INCH. SHADED GUNS ARE CORRECT IN GENERAL OUTLINE, DOTTED GUNS ONLY AS TO LENGTH.

ALL BACKING IS 18 IN. OF WOOD WITH 1½ IN. SKIN.

FRENCH GUNS.

PERFORATIONS.



A HOLE WITHOUT FIGURES MEANS PERFORATION UP TO 3000 YARDS: MAXIMUM RANGES OF PERFORATION LESS THAN 3000 YARDS ARE MARKED IN FIGURES.

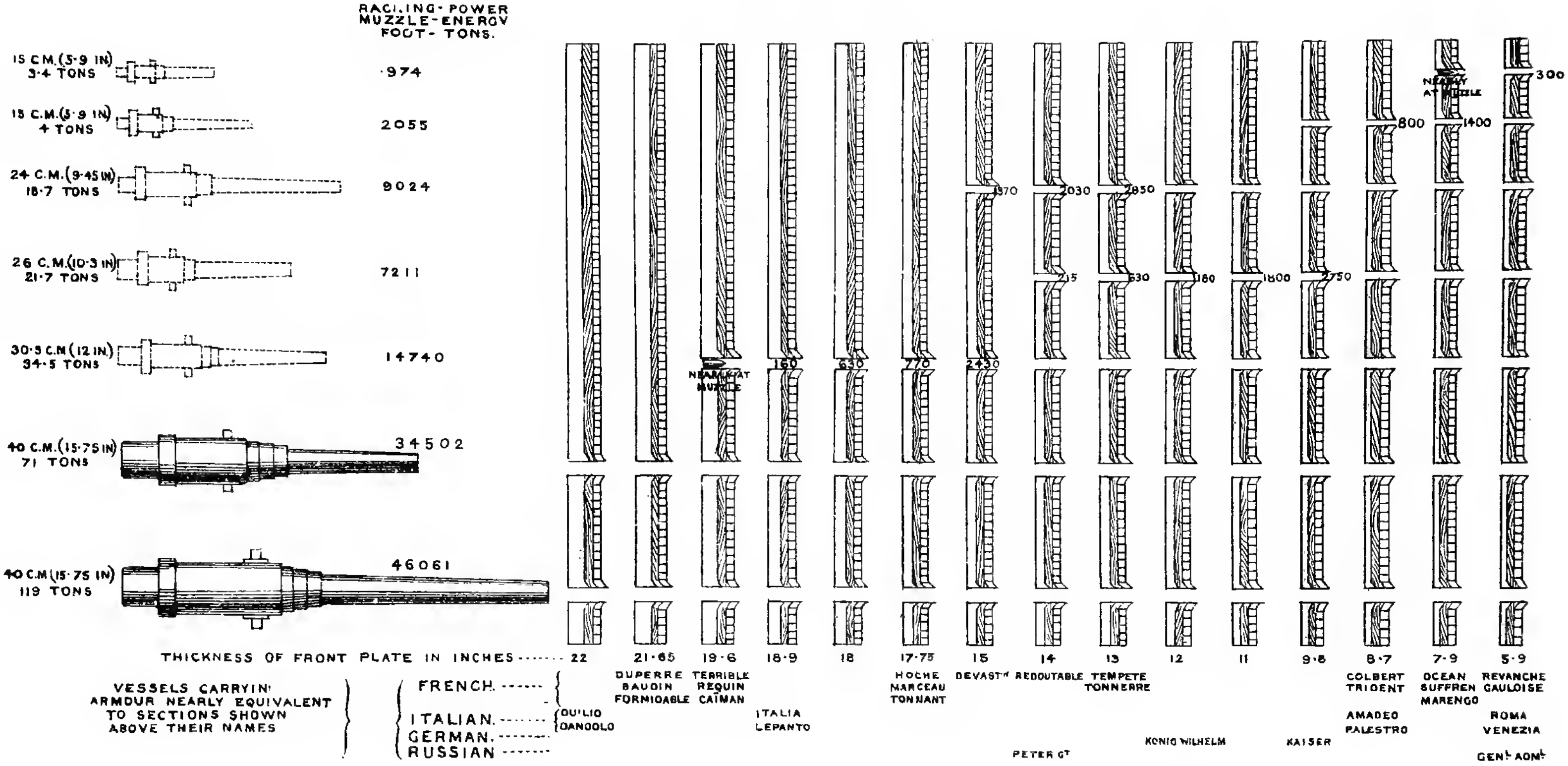
SCALE - 20 FEET TO AN INCH. SHADED GUNS ARE CORRECT IN GENERAL OUTLINE, DOTTED GUNS ONLY AS TO LENGTH.

ALL BACKING IS 18 IN. OF WOOD WITH 1½ IN. SKIN.

Pl. XVII.

GERMAN GUNS

PERFORATION



A HOLE WITHOUT FIGURES MEANS PERFORATION UP TO 3000 YARDS: MAXIMUM RANGES OF PERFORATION LESS THAN 3000 YARDS ARE MARKED IN FIGURES.

SCALE – 20 FEET TO AN INCH. SHADED GUNS ARE CORRECT IN GENERAL OUTLINE, DOTTED GUNS ONLY AS TO LENGTH.

ALL BACKING IS 18 IN. OF WOOD WITH 1½ IN. SKIN.

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